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Early strike forces of the future military are envisioned as being lightly armored to enable a rapid deployment. The increased vulnerability and operational tempo of lightly armored forces evokes the need for beyond-line-of-sight reconnaissance capability under the control of the troops on the ground. The objective of this work is to explore and evaluate system level concepts that fulfill this mission using an unmanned air/ground vehicle. As the world changes, so does the mission of the US armed forces. With these changing mission parameters, there develops a need for new and better weaponry and equipment not only to carry out new and unique missions but also to generally advance the state of the military art – providing not only fewer losses, but increases lethality as well. It is this environment of new and unique mission requirements that leads to the proposal of the Oiseau. The Oiseau is a proposed Aerial/Ground vehicle hybrid designed to fulfill the requirements set forth by the Concept Description Document (CDD) in a way that has never been done before. Using flapping wings, the Oiseau hopes to take advantage of good propulsive efficiency as well as relatively quiet operation for flight. The ground system will use lightweight tracks to traverse a wide variety of terrain. With advanced sensor and control systems, the vehicle will be able to meet the broad demands of the specification. With an anticipated deployment date of 2025, there is ample time for development of technologies required to make the Oiseau work. However, this time must be used wisely. A schedule has been created listing the technologies and when they should be operational.

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Integrated Unmanned Air-Ground Robotics System

Final Report – Volume III

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April 23, 2001

Executive Summary

English

As the world changes, so does the mission of the US armed forces. With these changing mission parameters, there develops a need for new and better weaponry and equipment not only to carry out new and unique missions but also to generally advance the state of the military art – providing not only fewer losses, but increases lethality as well. It is this environment of new and unique mission requirements that leads to the proposal of the Oiseau. The Oiseau is a proposed Aerial/Ground vehicle hybrid designed to fulfill the requirements set forth by the Concept Description Document (CDD) in a way that has never been done before. Using flapping wings, the Oiseau hopes to take advantage of good propulsive efficiency as well as relatively quiet operation for flight. The ground system will use lightweight tracks to traverse a wide variety of terrain. With advanced sensor and control systems, the vehicle will be able to meet the broad demands of the specification. With an anticipated deployment date of 2025, there is ample time for development of technologies required to make the Oiseau work. However, this time must be used wisely. A schedule has been created listing the technologies and when they should be operational.

French

Comme le monde change, les missions des Forces Armées Américaines doivent évoluer. Avec l'émergence de nouveaux paramètres de mission, se développe un besoin en armement nouveau et plus efficace non seulement pour effectuer ces nouvelles missions mais aussi pour permettre a l'Armée Américaine d'avoir toujours une technologie de pointe qui permette de réduire les pertes humaines et matérielles. La proposition faite pour répondre à cette demande est l'Oiseau. L'Oiseau est un concept de drone aérien et terrestre conçu dans le but de répondre aux besoins listés dans le cahier des charges (Concept Description Document CDD) de façon innovante. Grâce à l'usage d'ailes mobiles, l'Oiseau espère obtenir un bon rendement pour la propulsion mais aussi un fonctionnement silencieux durant la phase de vol. Le système au sol se compose de chenilles légères qui permettent au véhicule de fonctionner sur tous types de terrains. Grâce à un système de commande et des capteurs performants, le véhicule pourra remplir toutes tâches qui lui ont été assignées dans le cahier des charges. Considérant une mise en service en 2025, il reste suffisamment de temps pour permettre le développement des nouvelles technologies nécessaires au fonctionnement de oiseau. Cependant, ce temps doit être géré avec prudence. C'est pourquoi un calendrier a été crée dans lequel les nouvelles technologies ainsi que les dates auxquelles elles devraient pouvoir être opérationnelles.

UAGV Compliance List

This list is intended to provide a cross-reference for the specification and vehicle performance.

Specification:	CDD location:	Proposal location:
Minimum operational range of 15 km	1.2.2	XXX
Minimum payload capacity of 60 lb	1.2.3.1	XX
Moving payload to operational range in 30 min or less (same for return)	1.2.3.2	XX
Minimum cruise speed of 30 km/hr.	1.2.3.2.1	XX
VTOL capability	1.2.4.1.1	XX
Avoid sonic detection	1.2.4.3.1	XX
Near quiet acoustic signature	1.2.4.3.2	XX
Operational altitude: 0-500 ft AGL	1.2.4.3.3	XX
Minimum VROC: 250 fpm	1.2.4.3.4	XX
Capable of operating at 4000 ft altitude, 95 degrees, not using more than 95% intermediate rated power	2.1	XX
Nap of the earth flight capability	1.2.1	XX
Operational performance under adverse conditions	2.2	XX

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Common Terms and Acronyms List

Word	Comments
AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
AMCOM	United States Army Aviation and Missile Command
BLOS	Beyond Line of Sight
CAD	Computer aided design
CM	Communication
Concept Description Document	Document that details the customer's technical specifications for the UA/UGV
CST	Central Standard Time
Customer	John Fulda and Jim Winkeler
Dry Weight	
EE	Electrical Engineering
EH	English
EM	Engineering Management
EST	Editorial Support Team
ESTACA	Ecole Superieure des Techniques Aeronautiques et de Construction
FLOT	Forward Line of Troops
Ft	Feet
Fpm	Feet per Minute
IHVM	Integrated Vehicle Health Managment
IPT	Integrated Product Team
IRP	Intermediate Power Rating
JAUGS	TBD
JCDL	TBD
Joint Vision 2020	TBD
Km	Kilometer
LCD	Liquid Crystal Display
LRU	Line Replaceable Unit
lbs.	pounds
MAE	Mechanical and Aerospace Engineering
MKT	Marketing
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
nm	Nautical miles (~2025 yds)
Payload	Item carried by the system having a specified weight
Phase I	Baseline review, conducted on conventional configuration using current and experimental technology, assess technologies clarify the Concept Description Document
Phase II	Alternative concepts review, development and evaluation of four prototype designs to meet customer

	specifications. Select a preferred design.
Phase III	Final Evaluation, detailed design specifications of selected design concept
RCM	Reciprocating Chemical Muscle
RFP	Request for Proposal
RSC	Radar Cross Section
RSTA	Reconnaissance, Surveillance and Target Acquisition
RMA	Revolution of Military Affairs
Style Guide	Document that specifies the mechanics of writing documents required for the project
TBD	To be determined (not know at this time)
TBE	Teledyne Brown Engineering
TF/TA	Terrain following/terrain avoidance
UAH	The University of Alabama in Huntsville
UAV	Unmanned Air Vehicle
UGV	Unmanned Ground Vehicle
US	United States
VROC	Vertical rate of climb
VTOL	Vertical takeoff and landing

Team-Specific Terms and Acronyms List

Word or symbol	Comments
Cmax	Maximum Torque
C_D	Drag Coefficient
Cl	Lift Coefficient
D	Vehicle Dag
V	Vehicle Air Speed
W	Downwash
S	Planform Area
T	Thrust
b	span
c	Chord length
ρ	density

IPT 2: Feasibility of Unmanned Air/ Ground Vehicle (UAGV)

1.0 UAGV – Unmanned Air/ Ground Vehicle

1.1 The Need

An increased operational tempo (Op tempo) is imperative for future forces. As conflicts arise in many different countries, we must be prepared to rapidly move troops and supplies to any location in the world. The op tempo predicted for the next war is 50-100 km/h. This pace is significantly greater than that of World War II and requires vehicles that can move and negotiate terrain at greater speeds. The UAV/UGV is intended for use at the battalion level to assist medium and light forces and increase their effectiveness.

An increase in robotics is essential for the future Army. Due to a reduction in forces, fewer troops are available for service. Additionally, worldwide conflicts require these troops to be able to deploy rapidly to the point of interest. This ability to deploy quickly comes at a price to the soldier. No longer will heavy armor and the supplies that keep a soldier's vulnerability low accompany him. Robotics can augment the power of the troops by performing multiple missions without the risk to human life. The need for robotics exists to fill the gap for "dirty, dangerous, and dull" missions. The use of robotics may even eliminate the need for human forces to perform dangerous missions.

The Army wants to prevent casualties whenever possible. The CNN factor, meaning the extensive, publicly followed media coverage, demands a "clean" war for Americans. The UAV/UGV will function at the forward line of troops (FLOT) and beyond the line of sight (BLOS). Reconnaissance missions performed by soldiers on the FLOT are extremely dangerous, and are impossible BLOS. By performing these missions successfully and enhancing the reconnaissance, surveillance, and target acquisition (RSTA) capability of their respective battalions, the UAV/UGV will allow the FLOT to make more informed, and thus, better decisions.

The Army's missile and aviation systems must incorporate advanced technologies and robotics to remain viable in the future battlefield environment. A hybrid UAV/UGV fits perfectly into this picture.

1.2 The Requirements

AMCOM has tasked Pegasus Engineering to develop a future vehicle that integrates the capabilities of both a UAV and a UGV to perform missions normally performed by soldiers in the field. The requirements for this type of operational capability exist on three different levels. In the most general terms, the UAV/UGV must meet the Army's needs. This need calls for an intelligent, autonomous vehicle that is capable of performing a task. Therefore, the vehicle must be survivable, must be capable of maintaining the operational tempo, and must increase the reconnaissance, surveillance and target acquisition (RSTA) abilities on the battlefield.

On the second level, the vehicle must meet the mission/payload requirements. This involves the vehicle being able to fly to the objective area in 30 minutes in a nap of the earth flight

configuration while avoiding both obstacles and potential enemies. Upon reaching the deployment site, it must be able to either hover for 60 minutes or land on the ground and move itself, via ground propulsion, to the designated area. When the mission is complete, the UAV/UGV must then be able to return to its launch area.

Finally, the third level is the vehicle requirements. The vehicle requirements are the actual performance parameters that the UAV/UGV must meet to perform the mission. These involve the vehicle being able to fly at a minimum of 30 km/sec, with a 250 ft/min VROC at a maximum altitude of 4000 ft. An example of how these levels fit in with each other can be seen with this example. The vehicle requirement of being able to have a vertical rate of climb of 250 ft/min enables the UAV/UGV to meet the mission requirement of being able to fly in a nap of the earth configuration. Flying using this profile enables the UAV/UGV to avoid detection and therefore become more survivable.

The challenges to be overcome in this novel system are both technologically and integration based. The technology needed to have a truly "intelligent" system that can monitor, think and actually react to a situation is one of the largest challenges to meet. Artificial intelligence has come a long way, but is still in its infancy. Many communication methods still require the vehicle to be in the line of sight of the monitoring vehicle or the use of an orbiting satellite in order to send telemetry. Tying in the capabilities of a system that can operate in both the air and the ground has the biggest issue of weight. Current propulsion methods are bulky and usually involve a high specific fuel consumption. Cutting the weight down with lighter and stronger materials and coupling it with high efficiency engines is the challenge of today and the future of this type of vehicle.

1.3 The Solution

1.3.1 Concept Overview

The Oiseau, a French word meaning bird, is a UAGV capable of meeting the future needs of US military forces. Utilizing an efficient design and mating together both technology and simplicity, the Oiseau meets the need of providing direct intelligence support during dirty, dangerous, and dull missions.

Forward intelligence support is the essence of the Oiseau's capabilities. Using a Fuel Cell system, the Oiseau is able to fly without the noise associated with most motors. As it produces power for the four flapping wings, it also produces the electricity needed to power the on-board navigational, surveillance and communication equipment. With only water as a by-product, it is also an environmentally sound energy production system. The "intelligent" sensor and communication package allows constant beyond line of site (BLOS) communication to the soldiers viewing, in real-time, what the sensors on the Oiseau see. The flapping wing configuration allows the Oiseau to fly with agility only matched by real birds and flying insects. On the ground, most any terrain can be traversed with a tracked system, configurable by the soldiers for wet, dry or slippery conditions, that is able to move at 5 mph. Both on the ground and in flight, an active camouflage system makes this near silent vehicle almost invisible to the naked eye as it blends in with its surroundings. Damage to the internal

components, outer shell or wings of the Oiseau are easily replaced because all of these components are modular and thus easily removed and replaced/repaired.

The capabilities of this UAV/UGV are what make this vehicle stand alone as the future of intelligent robots for military use. Each component on its own is noteworthy, but the compilation of them in one system makes the Oiseau extraordinary. A couple of the most noteworthy components are first, the propulsion system. Because fuel cell systems are becoming more efficient and provide quiet power, it was the logical choice for a system that needs a near silent acoustic signature. It produces power without combustion, which keeps the thermal signature low, and runs on a minimal amount of fuel. It is coupled with the next noteworthy component, the extremely light weight wings made with titanium and Gore-Tex. These wings can be actively twisted and bent using piezoelectric materials along the wing's edge and allowing the flight characteristics of the wing to change instantly. ***(Note: the artists rendering and 3-D model does not accurately reflect final design changes)***

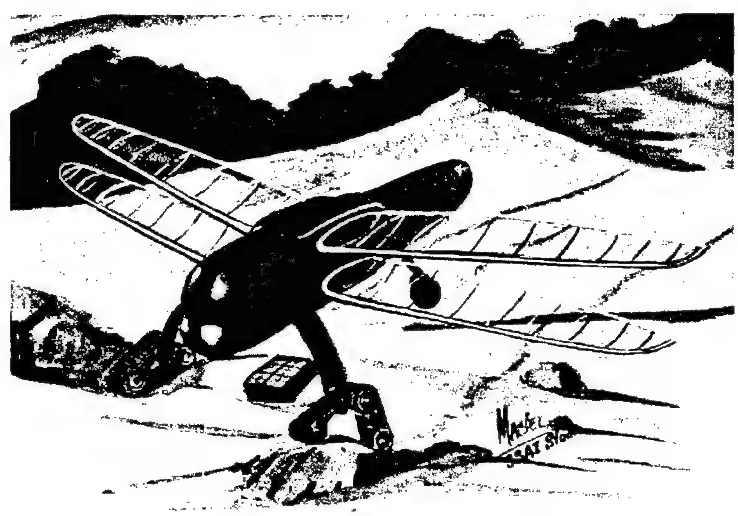
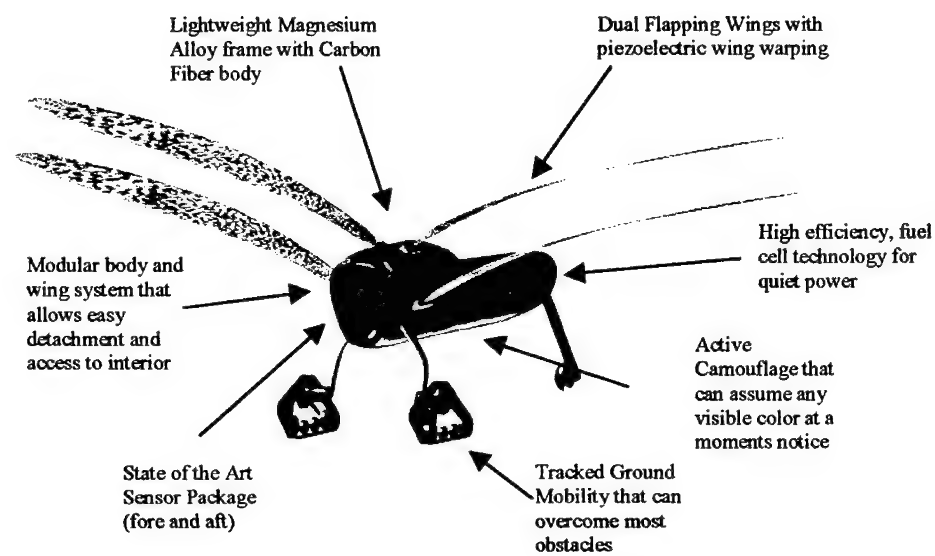


Figure 1. Artist Drawing



1.3.2 Dimensional Properties

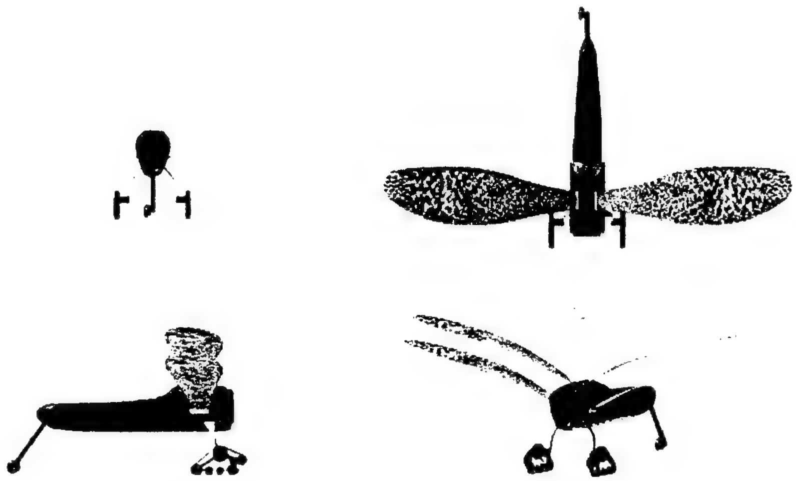


Figure 3. Three-View Drawing (Preliminary)

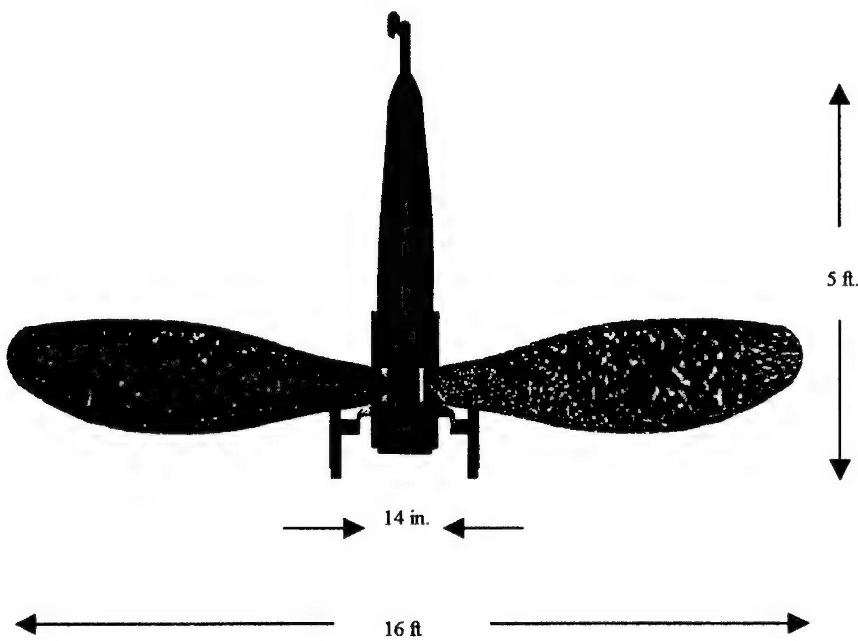


Figure 4. Dimensions

1.3.3 Operations Scenario

The assumed mission profile is for the vehicle to takeoff vertically close to the FLOT, climb at 250 fpm to a maximum altitude of 500 ft AGL (at high hot conditions), and cruise at 30 km/hr for 30 minutes (15 km range). The vehicle will then either hover for 60 minutes or land, traverse the ground, and takeoff again and then fly back to the departure point. The sensor package and payload capacity will give the Oiseau considerable flexibility in terms of the operations it can perform.

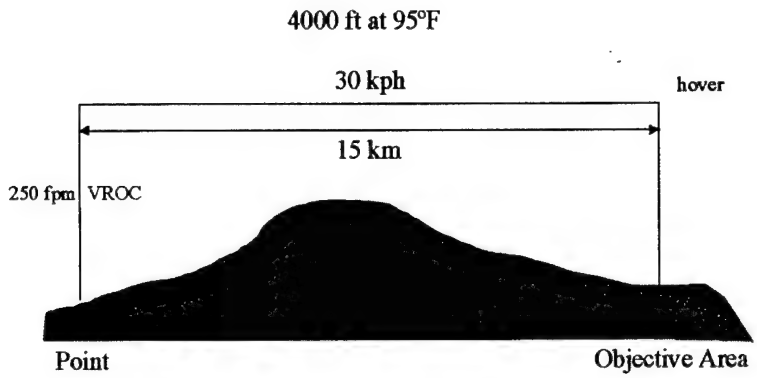


Figure 5. Operations Scenario

A typical battlefield scenario might occur something like this:

> As night approaches in the Balklands, an Army field commander orders the destruction of a bridge the enemy is using to re-supply its forces. After darkness falls, the Oiseau embarks from the forward command post and begins to fly over the FLOT towards the bridge 10 km behind enemy positions. After penetrating the enemy airspace, the Oiseau begins to glide toward the target - nearly silent. The vehicle lands in a nearby field (selected after sensors indicated that no enemy troops were present) and travels along the ground to a bluff overlooking the bridge. Once it receives signal that the strike fighters are nearly on target, the Oiseau then paints the bridge with an invisible targeting laser included as the payload. Seconds later, the approaching F-18 (from the nearby carrier battle group in the Adriatic Sea) detects the laser and, after making the final approach, drops the precision guided munitions and immediately returns to friendly airspace. After a successful hit, the Oiseau again takes off to return to the forward command station. En route, an army operator assumes control of the vehicle and orders it to observe the enemy's troop location and strength before ultimately returning home.

1.4 The Performance

This section presents a summary of the performance of your UAGV in comparison with specific details of the concept description document. Present the compliance matrix [required Table]. On quantitative requirements list the design value of your solution. Give adequate support of the Table through discussion in the text.

Table 1: Final Concept Evaluation

CDD Requirement	Requirement	Assessment	Remark
Range from launch point	15 km	30 km	
Cruise Speed	30 km/hr	40km/hr	
VROC	250 ft/min	360 ft/min	
VTOL Capability	Yes	Yes	
Payload:	60 lb	68 lb	
Operational Altitude	0 to 500 ft AGL	0 to 500 ft AGL	
Hover to full flight profile	Yes	Yes	
Operation	Autonomous or Semi-autonomous	Autonomous or Semi-autonomous	
Acoustic Signature	Near Quiet	Moderate to Near Quiet	
Communications	BLOS	BLOS	
Deployment	2025	2025	

1.5 The Implementation

There are several technologies whose further development is critical to the development of the Oiseau. One such technology is lightweight fuel cells and electrical motors. Fuel cells have been used for quite some time in spacecraft for the generation of electrical power; however, some adaptations are needed for the Oiseau. Although operating characteristics of electric motors are widely understood, a specific motor will have to be developed that is optimized for flight (i.e. high power to weight ratio, etc.). Another technology currently under development is Integrated Vehicle Health Management (IVHM). This is a computer software system that records: fault messages with Line Replaceable Units (LRUs) isolation, parametric and performance data, and warnings, cautions, and advisories

(http://technology.ksc.nasa.gov/wwwaccess/techreports/97/07-EI/ei07.html accessed 10 April 2001). This system can be used not only to schedule preventative maintenance, but to optimize sub-system performance as well. Another technology required is pizeo-electric materials to be used by the control system. These materials, also currently under development, distort their shape when voltage is applied to them. Such devices will be built into the flexible wings. This will yield control over camber for aerodynamic effects and wing warping for controls.

Further technological development required includes wing material and lighter structural materials. The requirements for the wing material are unique. Directional gas permeability is required for aerodynamic reasons. There exist fabrics capable of such characteristics; however, better performance is, of course, needed. Lighter materials in general could greatly effect the performance characteristics of the Oiseau. Current research in this topic is broad and the shows much potential.

The next area of study needed is the development of software that can handle the autonomous operation of a UAGV. There is considerable development of software in the commercial arena. Advance avionics packages should be developed to control the vehicle as it flies as well as coordinate the ground robotics.

There are considerable advantages to using flapping wing flight. However, there is considerable research work needed to fully implement the design. With an anticipated deployment date of 2025, there is ample time to complete supporting research. With this intended deployment date, detailed design will need to occur by 2016. The technology must then be available by this date to fulfill the specification. More specifically, the electrical propulsion system's research should be completed in the next 10 years (by 2011). The research for the wing material must be done in the next 12 years as well to allow for testing before detailed design begins. The software should be developed by 2011 as well and tested in an existing vehicle before 2014. The avionics should be developed in parallel with the software. The combination of the software and avionics should be tested before 2016.

2.0 Enabling Technologies

There are several aspects of the Oiseau's design that require in depth technical explanation to show the relative validity of performance claims. This section is aimed at doing just that.

First is the performance of the flight/propulsion method of flapping wings. This method of flight was chosen because of its possible power to weight benefits. Our evaluation is, admittedly, a back of the envelope type of calculation meant to give a rough idea of the wing size, power requirement, frequency of motion, and forward flight velocity capability. There is a significant amount of detailed work being done regarding flapping wing flight, most of which involves micro air vehicles. Although there are a number of complex aerodynamic models, our analysis is as simple as possible for two reasons: 1. Practical ability of the team to perform the analysis in the limited time frame and 2. Our purpose is to show that the Oiseau is technically feasible and cost effective.

The ability of the wings to generate lift and thrust is hinged on the availability of an advanced material, perhaps polymer or fabric, which retains directional gas permeability. The later term describers the ability of a thin sheet of material to allow for the passage of gas, in this case air, more easily in one direction over the other

Another technology that will enable our design to meet the specification is an advanced control system that utilizes pizeo-electric materials to warp critical areas of the wings. This technology, works by applying a voltage to pizeo-electric material that causes it to distort shape. The material is located along the sides and trailing edge of the wing, which act as control surfaces. Although control of a flapping wing may be difficult, it should be possible. A four-wing system is required for stability, and for VTOL and hovering capabilities. During sustained forward flight however, the rear wings will be held stationary while the forward wings provide thrust. This stationary wing, besides generating lift, will be used as a control surface.

Another design consideration is the measures taken to provide stealth characteristics to the Oiseau. One such measure is the application of radar absorbing paint to the outer body. This will be used to reduce the radar cross-section. Although the Oiseau is several times larger than a bird, the reduced cross section might fool enemy equipment into thinking the returned signal is actually biological in nature. Another stealth feature is the ability of the Oiseau to operate with a much lower acoustic signature than rotorcraft type vehicles – especially while soaring. Another feature that will be implemented is a lightweight, flexible LCD "screen" that can be used as a fabric. Currently under development by private industry, this will be installed over the outer skin of the vehicle to provide active camouflage while on the ground.

Another enabling technology is lighter and stronger materials. The need for this technology is nearly universal and the Oiseau is no exception. The vehicle will utilize a magnesium frame and carbon fiber outer skin. Magnesium was chosen for its good strength to weight ratio. Although not as economical as some alternatives today, it has the potential to rival the production cost of Aluminum in the future. The metal's light weight is of paramount importance to the vehicle's ability to perform.

The following sections discuss these and other enabling technologies in more detail, and discuss the method of our anaylsis.

2.1 Systems Integration

There are a number of factors that contribute to the overall results that the team has produced. A design philosophy of having literally no inhibitions to innovative solutions was encouraged. Given a 25-year time frame to work with, this trait is not only desired, but it is necessary as well. It is in this environment that the Oiseau was not only proposed, but also chosen.

We selected the Oiseau because it has the potential to have very attractive performance characteristics and has the most room for technological advancement in the next 25 years.

The design process used was to assign team members to areas of responsibility. Any particular team member would have a primary area of responsibility and at least one secondary area of responsibility. For example, the mechanical configuration team operated differently from the aerospace team. However, one person from each team was always in contact with a person from the other team. There were two primary reasons for this: it increased the number of people in each group so there was more than one head attempting to form a solution to a given problem and it would increase the communication across the disciplines.

The design philosophy the team adopted was that of a conceptual iterative design. While the analysis presented here is only one iteration, the ultimate vehicle configuration will go through many much iterations. Because this is a conceptual design and a first iteration, the calculations are not intended to be the definitive results, but a "back of the envelope" approach to showcase fundamental feasibility.

The design of the vehicle began by assuming a target weight of 400 pounds. Then, calculations were made regarding the lift required. Power requirements were then calculated to provide the VROC given by the specification. Using this data, a power source was selected and the amount of fuel calculated. The weight of the power source, fuel, propulsion components were then added together as well as all other components developed independently (sensors, ground robotics, etc.). This process yielded a weight of 332 lb without payload.

2.2 Aerodynamics

2.2.1 Approach/Configuration

Humans have been studying and trying to model the flight mechanisms of birds and insects now for many years with some success. The materials and processes needed to produce a vehicle that models bird flight are just now attaining a level of sophistication to warrant a serious design consideration. Birds have adapted their bodies over time to produce as much lift and thrust as possible while producing very little drag and downwash.

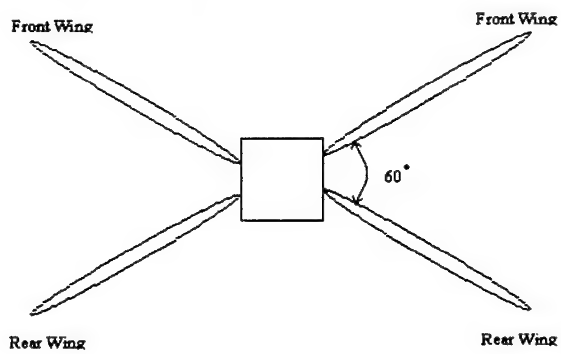
The majority of the lift that a bird produces comes from the downstroke of its wing. The quick motion downward with the wing cupped produces a drag force in the direction of the velocity of the wind flowing into the wing (see figure below). This drag force is in the positive direction and actually produces lift (Dryden 2001).

To avoid having an equal and opposite force on the upstroke, the wing is shaped so that the drag coefficient of the air flowing into the wing on top is less than that of the wind flowing into the underside of the wing. This forces the wing to have a small drag force in the down direction but the overall force for the entire cycle is positive.

Birds also spread their feathers slightly so that air can pass between them on the upstroke, thus reducing drag. This works the opposite way on the downstroke. Birds push their feathers together so that the air is trapped on the underside of the wing and all of the air velocity is used as positive drag (lift)(3). Another method they use to decrease drag on the upstroke is by bending the wing slightly. This decreases the planform area of the wing and thus produces less drag. Once again this is counteracted on the downstroke when the bird stretches its wing as far as it can so that the area seen by the airflow is maximum (1).

The configuration of the wings on the Oiseau is meant to take these factors into account and mimic them as much as possible using new materials. The wing of the Oiseau is shaped like a shallow cup turned upside down. This increases the drag coefficient during the downstroke and decreases it on the upstroke. To try and recreate the minimal drag, the wings are built using a directional, gas permeable material which allows air to pass through in one direction but not in another due to the molecular structure.

In order to mimic how a bird changes the curve of its wing during flight, piezoelectric material is used (see Wing Structure section for a more detailed description. This allows the Oiseau to change the camber of its wings slightly during flight. This combined with the wing pitched upward during the upstroke will help to reduce the drag effect of the upstroke. To prevent the drag that does occur during the upstroke from pushing the vehicle back down, primarily during VTOL and hovering, the Oiseau will have four wings beating in opposite cycles. The wings are offset from one another in both the vertical and horizontal direction. (see figure below). This allows for greater lift capabilities as well as stability and control (4). This design was chosen based on the fact that a single pair of wings flapping would have to be very large to produce the lift required and would cause the vehicle to move in an up and down motion. This way, the lift is shared by the wing and is constantly positive so the vehicle will still move due to the cyclical changes in the lift but the motion will be much less than with only one wing.



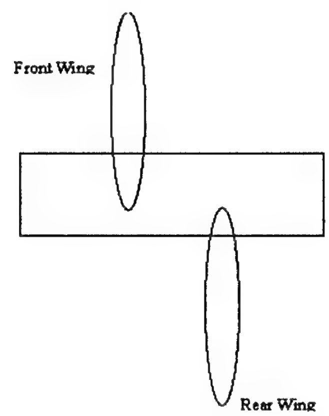


Figure 6 Front View of the Oiseau Right Side View

2.2.2 Flapping Wing Flight

The flight profile can be separated into three parts: VTOL, forward flight, and hovering. For VTOL, all four of the wings will flap in opposite directions with a shift in the phase of the cycle. This means that when the front wing is flapped to its maximum angle, the rear wing is in its minimum angle. The two wings then return to the horizontal position and continue to the opposite extreme. This produces a component of lift that is constantly positive, which provides added stability. The vehicle will lift off of the ground and continue up instead of lifting up and then falling down some of the distance it just rose as would happen if one wing were flapping.

The amount of lift is determined using the equation:

Equation 1 $$D = \frac{1}{2} * \rho * V^2 * S * C_D$$

From this equation, a component of drag is calculated based on the drag coefficient of the wing shape based on if the air is flowing onto the top of the wing or onto the bottom of the wing. Since the drag coefficient is greater for the downward motion, a greater force of drag is produce than on the upstroke. The force asserted on the wing is in the direction of the air flowing into the wing. Since the air is flowing into the underside of the wing on the downstroke, the drag force during the downstroke is actually in the positive vertical direction. Also, since the drag coefficient is greater during the downstroke, a net force in the positive vertical direction results from one complete cycle. For the vehicle to lift off of the ground, this net force must be greater than that of the vehicle weight during both the vertical takeoff as well as horizontal flight.

Based on a density (ρ) of 1.08 kg/m^3 (the density at 4000 ft), a CD of 1.4 on the downstroke and 0.4 on the upstroke, a planform area is approximately 35 ft^2, the total lift of the four wing configuration during vertical takeoff is just over 2000 N. This is around 175 N more than is required to counteract the weight of the Oiseau. This assumes that velocity of the air is equal to the velocity of the wing during its movement. Since the wing velocity changes throughout one cycle, the value of lift was integrated over one cycle with the value of velocity changing. This assumption was made because the velocity of the wing in still air is equal to the velocity of air on a still wing. Although these calculations were first order estimates, results indicate the validity of the Oiseau's design.

Once the Oiseau reaches its operating altitude, the rear wings slowly decrease their rate of flapping until they stop completely. The forward wings will use the piezoelectric material to change camber and the wing will tilt slightly to produce not only lift but also thrust. During the downstroke, the wing will be given a negative angle of attack so that the force on the wing is directed up and forward. On the upstroke, the wing is given a positive angle of attack so that despite having a component of downwash, there will be a component of thrust pushing the vehicle forwards (see figure below).

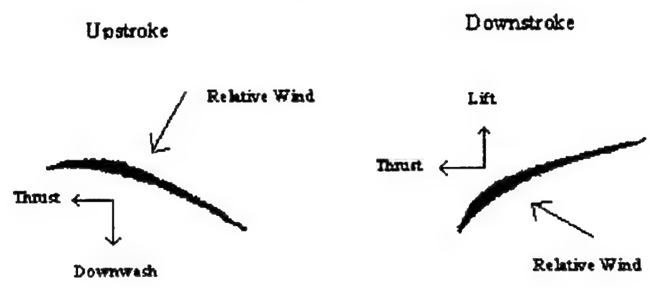


Figure 7

The thrust and downwash/lift are calculated using the equation above taking into account the angular change of the relative wind from the straight up and down motion. This angle is the same as the angle of attack and for the thrust is the sine of the angle of attack and for the downwash/lift it is the cosine of the angle of attack.

$$T = \frac{1}{2} * \rho * V^2 * S * C_D * \sin\alpha$$
$$L = \frac{1}{2} * \rho * V^2 * S * C_D * \cos\alpha$$
$$W = \frac{1}{2} * \rho * V^2 * S * C_D * (-\cos\alpha)$$

For the upstroke only the downwash (W) is used in calculations and the lift (L) is used in calculations concerning the downstroke. The thrust (T) equation is used for the entire cycle because thrust is constantly positive throughout the cycle due to the change in angle of attack from the upstroke to the downstroke.

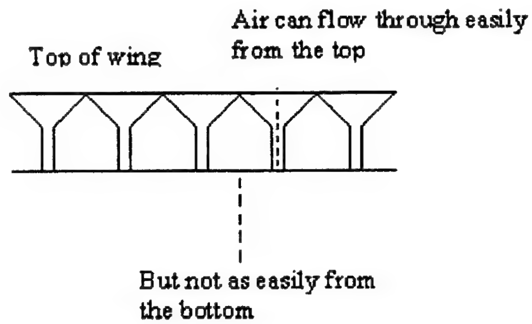
Using an angle of attack of 5.6 degrees, two wings flapping, 2 Hz, as well as the same parameters from the vertical takeoff calculations, the lift was still just under 2000 N and the thrust is 19 N. This thrust produces a forward velocity of 50 km/hr, 20 km/hr more than the minimum requirement. This calculation was once again obtained by integrating over the change in velocity throughout the cycle and taking into account the effect of the angle of attack of the wing (White 1999).

The mechanism for hover is much the same as that of the VTOL. All four wings will flap in opposite periods to control the motion of the vehicle body. They will return to a zero degree angle of attack and produce no forward thrust, only lift. The wings will be able to flap at a slower frequency than during the vertical takeoff since they will only have to overcome the weight and not increase altitude also.

2.2.3 Wing Structure

The wing is shaped somewhat like the fin of a sea turtle. This helps increase the lift slightly. Since the maximum velocity is at the tip of the wing, increasing the wing area there increases two parameters in the equation of lift. This takes advantage of the increased velocity for flapping wings, where a regular fixed wing that tapers at the end would not. In addition, the elliptic-like shape of the wing decrease the induced drag of the wing (5)

The figure below shows a cross section of the directionally permeable wing material. This was chosen because of its ability to allow air through on the upstroke and trap it under the wing on the downstroke (see the figure below).



This helps reduce the amount of downwash that occurs during the upstroke, which in turn reduces the amount of lift lost due to this downwash. This helps to mimic, somewhat, the way a bird allows air to flow through its spread feathers on the upstroke and trap the air under the contracted wing on the downstroke.

The use of piezoelectric material also helps with the lift as well as control. The material works using sensors and electric voltage. The material will deform slightly with an inputted voltage. Using this material at the outer and trailing edges of the wing will allow it to change shape during flight. The wing will be able to make small changes to its camber as well as work as flaps and ailerons do on a fixed wing aircraft. They will move the edges of the wing up and down to make the minor changes that a bird makes using tiny movements of its wings and feathers. The location of the piezoelectric material is shown in the figure below as well as the supports at the leading edge and within the wing itself to help with the structural integrity of the wing. So that the material can be used to its full potential, only one thin layer will be used and the supports will be underneath, similar to a kite.

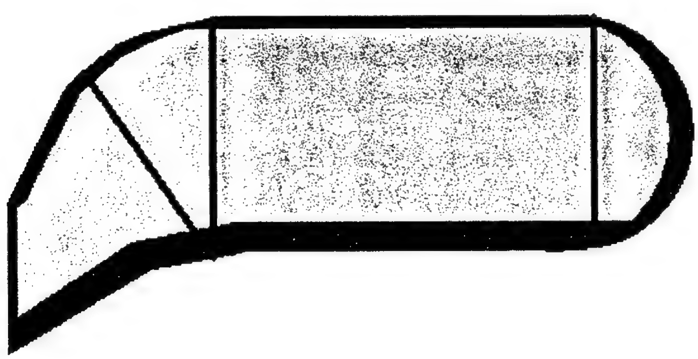


Figure 8 Top view of one wing

Overall, this configuration of wings, shape, and material are the critical components of flight for the Oiseau. They are what provide the vehicle with the thrust and lift required for completing the mission objectives. The Oiseau not only completes the mission objectives but also goes beyond the minimum requirements desired in some aspects of flight using state of the art techniques and materials as well as providing for a new concept to that of unmanned vehicles.

2.3 Propulsion

2.3.1 Description

The propulsion system of Oiseau is divided into three main parts: the energy's production, the motor and the transmission of the power to the wings. The energy is provided by a fuel cell, using hydrogen as fuel. The electricity produced can be used either for the electrical motor generating the flapping motion, or for the ground robotic system. Then the transmission system converts the spinning movement into an "up-and-down" motion.

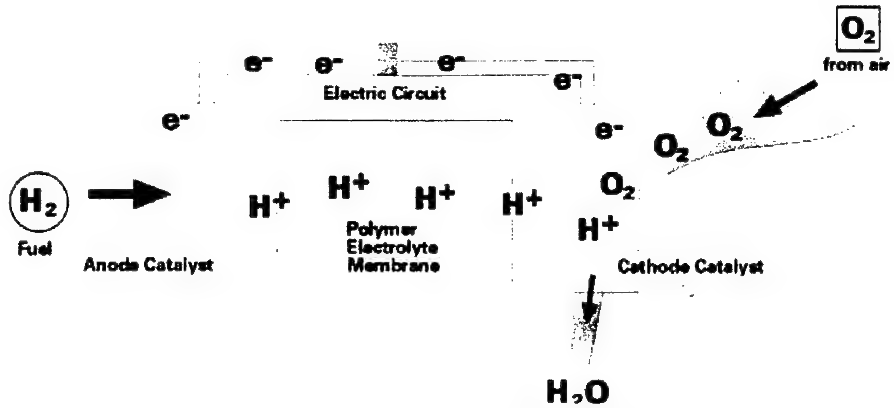
2.3.2 Approach

In order to design a relevant propulsion system, we focused, during our researches, on several requirements that it should fulfil. First the Oiseau has to be as noiseless as possible, second is, the energy used has to be easily available in 25 years. These are the reasons why we decided to use an electric motor. Once this choice made, the challenge was to find a source of electricity neither too heavy nor too big. Traditional batteries are not convenient because the power needed would require many batteries. Such a solution would have been too big, in term of volume, and also too heavy. Considering all the research and progress done during the past few years, fuel cells appear very promising and it will overcome these problems. Furthermore, and that was part of our requirements, this technology is now under development, a lot of private companies invest money in this research. Many automotive manufacturers are racing to be the first to bring a fuel cell vehicle to the marketplace. Automakers and component suppliers are spending billions of dollars to drive fuel cell technology toward commercialization. We can reasonably expect that in 20 years, all these researches will be completed and progress done.

2.3.3 Fuel cell

In principle, a fuel cell operates like a battery. Unlike a battery, a fuel cell does not run down or require recharging. It will produce energy in the form of electricity and heat as long as fuel is supplied.

A fuel cell consists of two electrodes sandwiched around an electrolyte. Oxygen passes over one electrode and hydrogen over the other, generating electricity, water and heat (http:// www.fuelcells.org . Accessed April 10, 2001.).


O_2
from air
e-
Electric Circuit
H_2
Fuel
Anode Catalyst
H^+
Polymer
Electrolyte
Membrane
Cathode Catalyst
H_2O

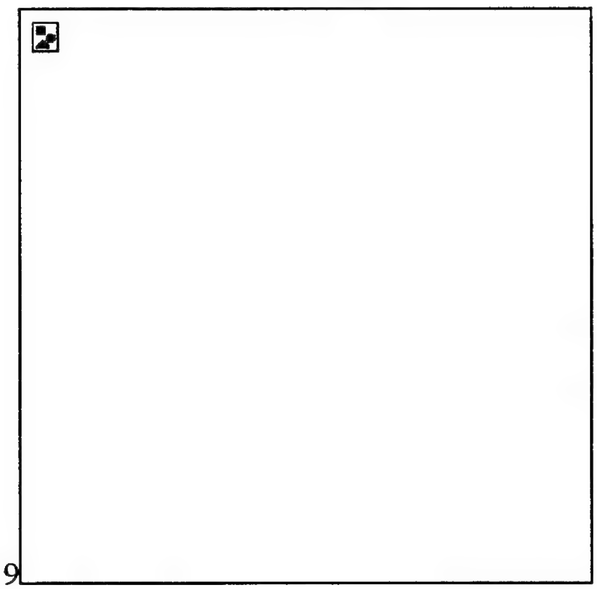
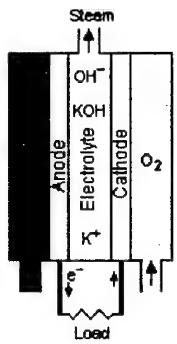


Figure 9

Hydrogen fuel is fed into the "anode" of the fuel cell. Oxygen (or air) enters the fuel cell through the cathode. Encouraged by a catalyst, the hydrogen atom splits into a proton and an electron, which take different paths to the cathode. The proton passes through the electrolyte. The electrons create a separate current that can be utilized before they return to the cathode, to be reunited with the hydrogen and oxygen in a molecule of water.
A fuel cell system, which includes a «fuel reformer», can utilize the hydrogen from any hydrocarbon fuel - from natural gas to methanol, and even gasoline. Since the fuel cell relies on chemistry and not combustion, emissions from this type of a system would still be much smaller than emissions from the cleanest fuel combustion processes.



Oxidation: $2H_2(g) + 4OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$
Reduction: $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

Figure 10

Not only do they produce reasonable efficiencies in 30 kW sizes; they will likely be able to run quietly, need infrequent maintenance, emit little pollution and have high efficiency even at part load conditions.
Electricity is used by many of our modern high technology devices. Presently batteries are used in these devices. Batteries do not have a long enough life for these applications. Fuel cells could provide continuous power for these devices. Every week or month a new supply of liquid fuel would be injected into the fuel cell.
Fuel cells are being proposed to replace Otto or Diesel engines because they could be reliable, simple, quieter, less polluting, and have even greater economy.
Fuel cells are most ideal for electric power production because electricity is both the initial and final form of energy that is produced.
Fuel cells are still a few years away from commercialization on a large scale. It is very difficult to tell which fuel and which technology will be predominant in the future. There are some problems to be solved. If these can be solved then these will become the predominant fuel cells being developed in the future. In the last year there has been considerable progress made in this direction.

Now, thanks to the progress done, fuel cells reach characteristics of weight and compactness compatible with our requirements: 1kg/kW and 1dm ^{3}/kW (Bezian, 1998).

Considering the power required by the motor which is 34.5 kW the fuel cell needed for Oiseau will weigh 35 kg (67 lbs.) and its volume is 35 dm ^{3}.

As companies who build these fuel cells design them for the specific automotive field, there are still no fuel cell fitting the exact characteristics of Oiseau. That is the reason why we can not present references here.

Arthur D. Little says, "The opportunities for further improvements in PEM fuel cell technology are impressive, further emphasizing the potential role of the technology as a major worldwide standard beyond 2000." (Little, 1996).

Fuel cells can promote energy diversity and transition to renewable energy sources. Hydrogen-the most abundant element on Earth- can be used directly.

Fuel and tank:
Carbon nanotubes are a new method for the storage of hydrogen. One way carbon can arrange itself is in a sheet pattern like a honeycomb. This is the graphite form of carbon. The sheets are not bound tightly together, but if they are wrapped on top of each other, a very strong carbon nanotube is formed. Carbon nanotubes were discovered by Terry Baker, professor of chemistry at Northeastern University, while Terry was doing research at the Atomic Energy Authority in Harwell, England. The carbon was a waste product of catalytic reactions. As a catalytic reaction proceeds platelets of precipitated carbon stack below and above the metal particle. Different metals of course, produce different configurations of the platelets. The carbon may stack like crackers, some may stack slanted end to end resembling a herribone, and some may stack in a bent formation creating tubes. A consistent property of the nanofibers is that the distance between each platelet is identical. The fibers are generally 5-100 micrometers in length and have a diameter of 5-100 nanometers, hence the name carbon nanotube. It has also been discovered that treating the nanotubes with nitric acid will open the caps on the end of the tubes. The interesting part concerning these carbon nanotubes is that their widths are just large enough for hydrogen molecules but too small for larger molecules. A typical hydrogen molecule consists of two hydrogen atoms. The hydrogen atom has the second smallest radius of all elements because its one electron is in the first orbital which is the closest orbital to the positively charged nucleus. So the one electron is held very tightly to the nucleus thus decreasing the atomic radius. It is possible then that perhaps hydrogen can be stored in these carbon nanotubes.

Terry Baker realized the possibility of storage in carbon nanotubes. His research findings have produced astounding results they have been able to store 30 liters of hydrogen in one gram of carbon! This corresponds to approximately 75% hydrogen storage by weight. At this rate a 25 liter tank which is half the size of a gasoline tank and weighs 87 kg can power a car for 5,000 miles. These experiments have been repeated fifty times by Baker.

The following general process is followed to allow hydrogen to be stored in the carbon: The nanotubes are first washed in acid to remove any metal impurities, they are then heated to 900 degrees C and put under a vacuum to remove any gases that may be slits on the nanofibers. Hydrogen is then pumped into the system at a pressure of 120 atm. The hydrogen can then be released by gradually reducing the pressure. Note a pressure of 40 atm must be applied to keep the hydrogen in place. The pressure where the hydrogen gas will cease to be released from the carbon tubes has also yet to be determined (Little 1996).

Assumption: considering that a 25 liter tank which is half the size of a gasoline tank and weighs 87 kg can power a car for 5,000 miles. And that an electrical engine of such a car required 33 kW (Toyota's Prius). Oiseau need the same power but the mission requires only to be able to do 36 miles (75 km). So by using proportionality we can figure out the weight and size of the fuel tank:

Equation 2 Weight of the fuel tank = (36 * 87) / 5000

= 0.6264 kg = 1.4 lbs.

Equation 3 Volume = (0.6264 * 25) / 87

= 0.18 liter tank

Fuel cells produce electricity. This is not the desired form of energy for transportation. The electricity must be converted into mechanical power using an electric motor.

2.3.4 Motor

The power required at the output of the motor for the flapping wings is 32.2 hp. Here are the references of the motor that we chose: it is an engine designed by the company BLADOR (http:// www.blador.com/information . Accessed April 14, 2001).

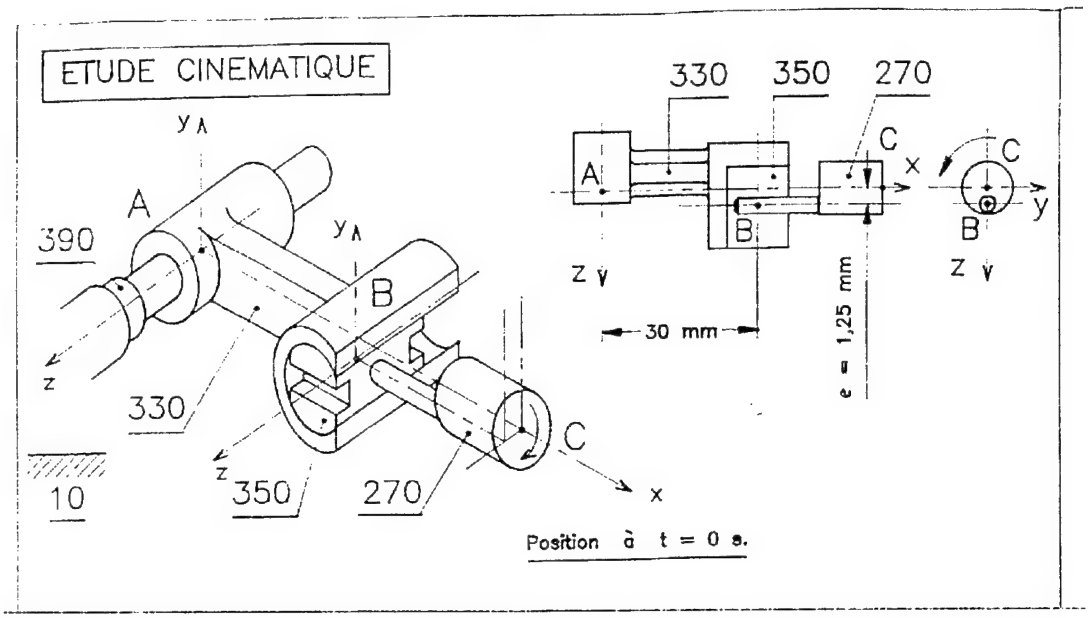
Type: BC20H440-CL

Which develop a power of 40 hp, and need an alimentation of 460 V and 75 A (as P=U*I, we have here P= 34.5kW which is the value used for the sizing of the fuel cell.)

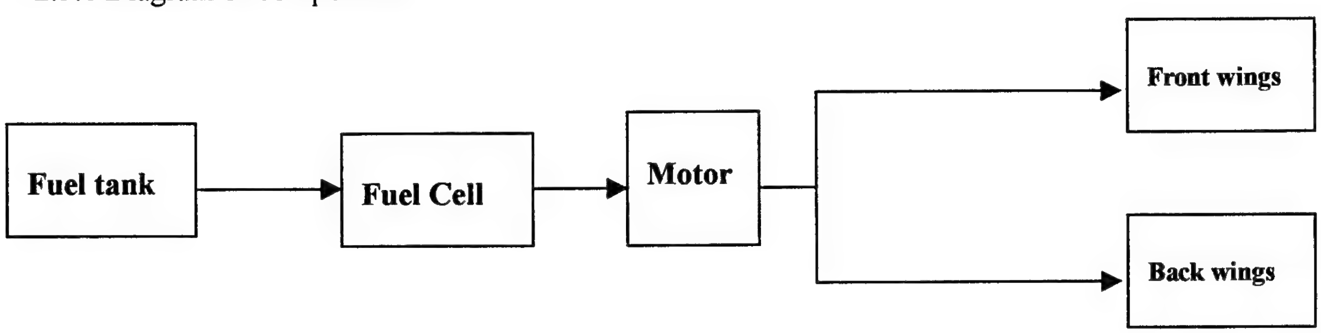
This motor weighs 60 kg (132.3 lbs.), but we can expect the within 20 years the electrical motor's weight will be reduced by 10 to 20% (Mr BONAFOS teacher and Dean of the Motor engine laboratory at SUPELEC Paris), so we based our calculation of weight on the value of 112 lbs.

2.3.5 Transmission system

The output of the motor is a rotation speed on a shaft; we need to convert this motion into an up and down motion, so that our wings will flap. The drawing below is not at scale, but shows the principle of our transmission system.



2.3.6 Diagram of components



2.3.7 Specification summary

Component	Specification	Weight	Size
Tank		1.4 lbs.	0.18 liter
Fuel Cell		67 lbs.	35 liter
Motor	BC20H440-CL	112 lbs.	
Transmission		10 lbs.	

2.4 Ground Robotics

2.4.1 Ground System Overview

To meet various terrain challenges, tracks were chosen for ground mobility. Initially a diamond shape configuration was considered. That included two tracks on the side of the vehicle and two tires, one in the front and one in the back. The final configuration eliminates the front non-powered wheel due to weight considerations. The two tracks on the side were increased in size, moved farther apart and placed further in front to make the vehicle more stable on downhill grades. Tracks were designed with six gears, with only one powered drive wheel. Two shock absorbers were designed, one for the powered gear and the other to the chassis of the track. The diagram of the whole track with all the components is shown below in Figure 11.

An electric motor is going to be used to provide power to the tracks. The rear tire will not be powered. The specifications, motor selection process and weight calculations are shown below. The ground maneuverability depends on the two tracks. It utilizes a process known as differential steering which moves one track at a time while keeping the other stationary.

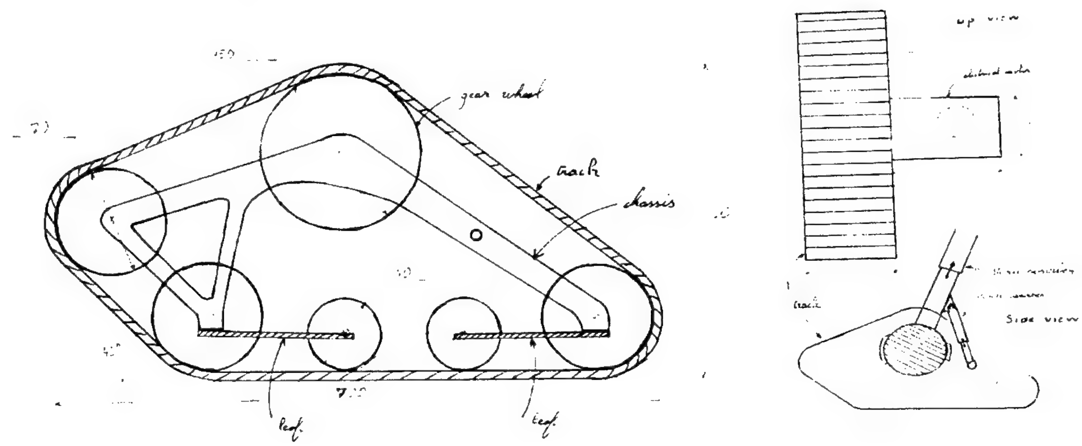


Figure 11

2.4.2 Power Required Calculations

In order to design the electrical motor, some educated guesses on the ground robotic capabilities were made. This hypothesis was made by researching data from other vehicles used for similar missions.

Max. Speed: $s = 10$ km/h (3.94 mph)
Pegasus weight: $m = 350$ kg
Max acceleration: $a = 1\ m/s^2$
Max slope: $\alpha = 30°$
Motor wheel diameter: $r = 15$cm (5.9 inch)
Gravity: $g = 9.81$ N/kg

Speed rotation

Equation 4 $$P = 2\pi\left(\frac{r}{2}\right) = 47.124cm = 18.55in$$

Equation 5 $$\frac{(s \cdot 1000 \cdot 100)}{60 \cdot P} = 353.68rpm$$

Motor wheel perimeter: P=2.π. (r/2)= 47.124cm (18.55 inch)
Motor wheel speed rotation: (s.1000.100)/(60.P) = 353.68 rpm

Max torque (Cmax)

The next equation is derived from the point of maximum acceleration located on a slope of 30 degrees.

Equation 6 $$ma = -mg\sin(\alpha) + \frac{2C_{max}}{r}$$

Equation 7 m.a = - m.g sin (alpha) + 2.Cmax/r

Equation 8 C_{max} = 77.5 N.m

<u>Final definition of Speed and Required Power</u>

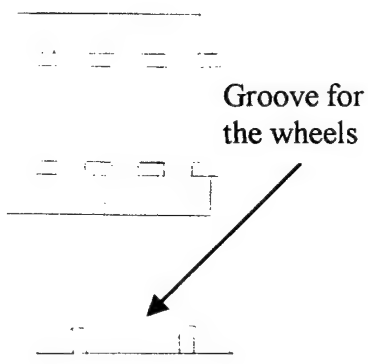
At the end, comparison of the actual electrical motor (for example: http://www.a2v.fr) which has a rotation speed between 5000 rpm and 6000 rpm, made us decide to use a reducer of 17. So the final motor electrical specifications are:

- Max rotation speed: 6000 rpm
- Max torque: 4.5 N*m
- Reducer of 17
- Motor weight: 6.5 kg
- Reducer weight: ~ 2kg
- Total power required: 8 kW

2.4.3 Ground Robotics Mass Definition

Mass for the robotics platform is divided into several different areas:

A) Track Material



For this element, polyclorure of vinyl (PVC P) is used because it is supple, resistant and has a good corrosion resistance. The volume mass is 1160 kg/m^3

- Section: 18.5 cm
- Perimeter: 2.33 m
- Weight /rubber track: 4.94 kg

Figure 12

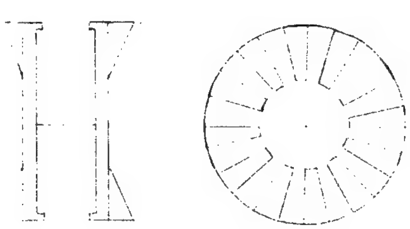
B) Wheels

The wheels on the Oiseau will be made from PVC U. This material is in the same family as the track material, but is rigid in comparison to PVC P. Each wheel is double and the volume mass is 1350 kg/m^3

- Volume (diam. 7 cm) : 53.8 cm^3
- Total weight/track (D: 7cm): 436g
- Volume (diam 4cm) : 21 cm^3
- Total weight / track (D: 4cm): 113g
- Total weight/track: 549g

Figure 13

C) Motor Wheel



Because of the torque and subsequent stresses involved in driving the main wheel of the assembly, aluminum is used as the material. Rubber track notch length is 2cm, so we have 12 notches on each wheel. The aluminum volume mass is 2800 kg/m^3

- Volume/wheel: 236 cm^3
- Weight/wheel: 660g
- Total weight: 1.32 k

Figure 14

D) Structure

Aluminum is used to combine both a lightweight structure with mechanical strength.

- Volume structure: 352 cm^3
- Weight / track: 985g

E) Motor

The weight of the electrical motor was estimated to be 18-20 lb. This number was obtained by comparing currently available electrical motors, which can be used for the ground robotics. It is expected that increases in efficiency and materials will allow a decrease in this weight in the years to come.

F) Tail wheel

Using currently available parts, the weight of back wheel was calculated to be 4kg.

Using the above components A - F, the total weight of the ground robotics system is 83 lb. A total weight of approximately 100 lb. is realized, if the track and wheel struts are included along with the other elements like ball bearings, and attachment hardware.

2.5 Sensors and Communications

The Sensors and Communication design utilizes an "Open System Architecture" approach. Interfaces and interface standard are very important to the overall sensors, communication, and navigational concept of Oiseau. When new or updated equipment is designed or acquired , it can be interfaced without new interface development - simply "plug-n-play". This promotes interoperability between the development of each service.

2.5.1 Communication

2.5.1.1 Mission Planning System

The mission planning system consist of Master Control Element (MCE)(10), with a Launch and Recovery Element (LRE), and space and ground communication equipment that form the Air-to-Ground Communication Segment (A-GCS). This segment is responsible for operation and control of the Oiseau.

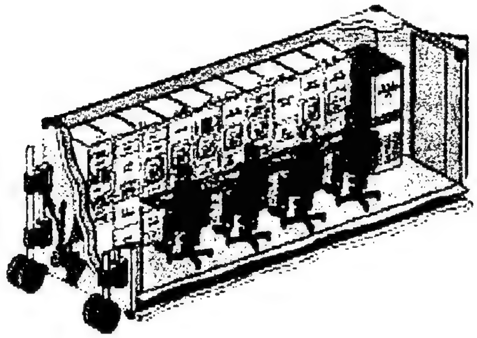


Figure 2.5.1: Diagram of the MCE Shelter(14)

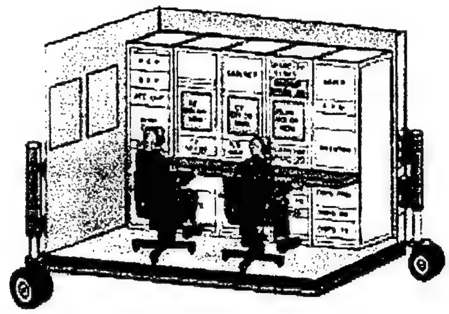


Figure: 2.5.2: Diagram of the LRE Shelter(14

The Master Control Element is responsible for key elements of the mission plan including flight, communications, sensor, and dissemination planning, sensor processing, deployment of spy_Oiseau("UCAVs & MAVs", 01 Feb 2001.), a surveillance micro aerial vehicle, and aircraft and mission payload control.

The Launch & Recovery Element verifies the health and status of the vehicle subsystems and loads the mission plan . During launch and recovery, the LRE is responsible air and ground vehicle control, coordination with spy-Oiseau and Oiseau and MCE. The Control of the UAV is handed over to the MCE by the LRE once the aircraft is airborne if in autonomous mode.

The CGS is designed to provide theatre commanders with continuous all-weather surveillance capability and intelligence. It is designed as separate elements to permit operation in geographically dispersed areas. Through C2 links, both elements remain functionally connected at all time.

The Command and Control window display UAV/UGV location, flight paths, mission target, flight control status, altitude, survivability information and flight control data (see figure 2.5.3).

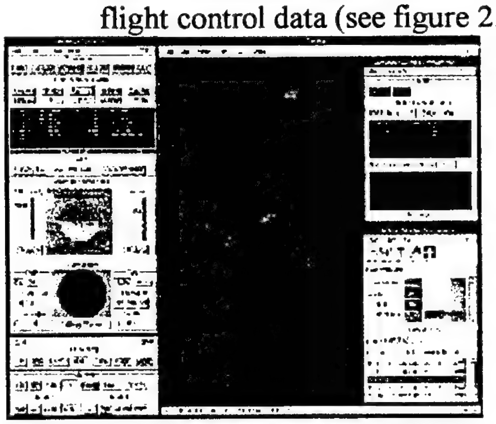


Figure 2.5.3: Command and Control Window(14)

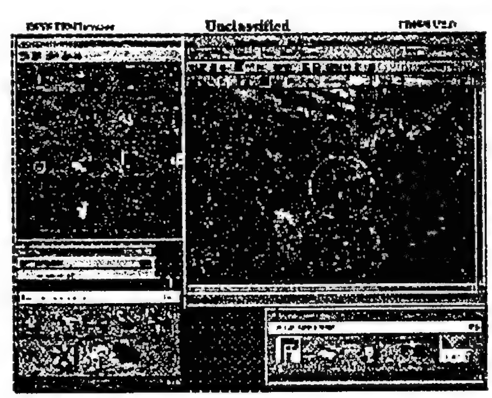


Figure 2.5.4: Imagery Control Window(14)

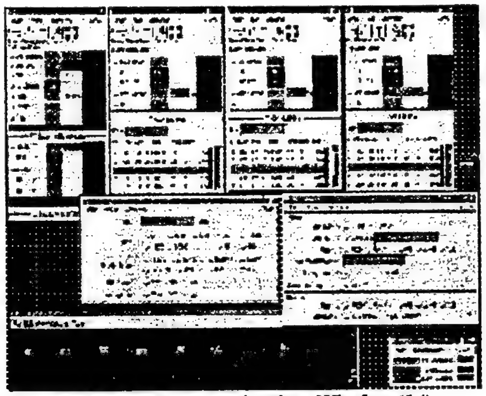


Figure 2.5.5: Communication Window(14)

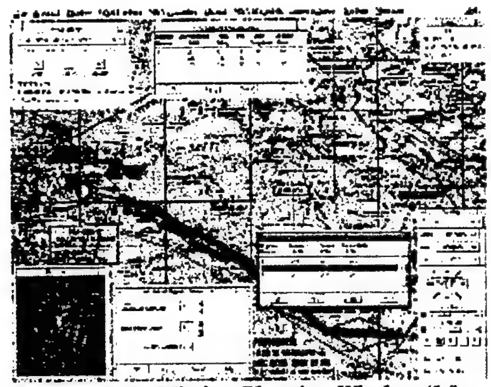


Figure 2.5.6: Mission Planning Window (14)

The Imagery Quality Control (figure 2.5.4) positions monitor the status of the payload and imagery output of the system. Imagery can be displayed at the QC position to provide quick-look support to the war fighter for battle damage

The Communication (figure 2.5.5) position monitors the status of the communication equipment and links provides support to the mission planner and overrides the existing communication.

The ground station for the Oiseau also consists of VHF transmitters and receivers as well as hardwire connectivity with the TROJAN SPIRIT II satellite communications terminal for back-up (BLOS) over-the-horizon communications.

Sensor data obtained from UAV/UGV are transmitted to the MCE via wideband RF line of sight or satellite datalink. Data are then disseminated in near real-time to existing command and control systems thru secure wireless network Interface.

2.5.1.2 Spy_Oiseau

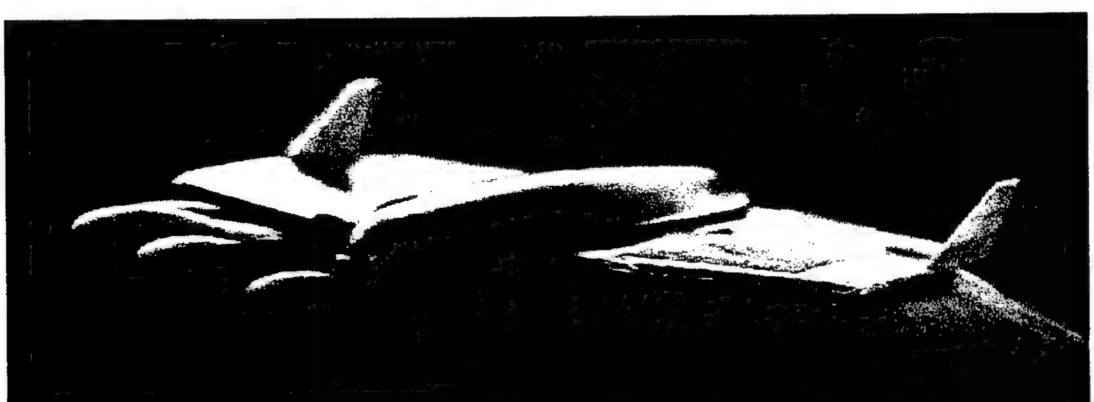


Figure: 2.5.8 MicroSTAR. Sanders, in collaboration with partners that include Lockheed Martin Skunk Works is developing its MicroSTAR under contract to DARPA

Spy_Oiseau is 3-inch micro aerial vehicle lanched from Oiseau that forms various sensing missions. Equipped with a with real-time imagery transmission via a digital datalink.("UCAVs & MAVs", 01 Feb 2001.) The CCD camera is a light sensitive silicon solid state device composed of many small pixels. The light falling on a pixel is converted into a charge pulse which is then measured by the CCD electronics and represented by a number (0-65,535). A digital image is the collection of such light intensity numbers for all of the pixels from the CCD. The system computer will reconstruct the image by varying the light intensity for each spot on the computer monitor in the proper order. This digital image linked to Oiseau and A_GCS.

The complete payload will utilizes Chip-On-Flex this shaves away excess weight from the package that isn't critical to operation of circuit.

Each major aircraft function, stability, navigation, data transmission, imaginary, processor, sensor, communications, flight, and processor will have its own 'tile" making future upgrading easier. Once created these titles are placed on a flexible sheet and the circuit becomes part of the aircraft, which also aids in heat transfer during flight.

Spy_Oiseau is fully autonomous flight vehicle, controlled by an uploaded flight plan input from Oiseau or the master control station. From a map display from Oiseau or the master control station the user selects waypoints and a flight path. Spy-Oiseau fly the preprogrammed flight path. Down linked imagery is reviewed directly on the MCS and Oiseau then transmitted to other interested users. The configuration for spy_Oiseau is included in Oiseau and MCE.

2.5.1.4 Operational Status

Development continuing,
Prime Contractor: Sanders Defense System(a Lockheed Martin company), Nashua, New Hampshire
Customer: US Defense Advanced Research Projects Agency (DARPA) and the US Army Research Office
Costs: DARPA funded. projected cost US$1000.00 each.

2.5.1.7 Concepts

2.5.1.7.1 Operational Concept: A minimum crew of three, comprised of two MCE operators and one LRE operator.

2.5.1.7.2 Maintenance Concept: The maintenance concept for Spy-Oiseau and Oiseau follows the general direction and guidance provided by the United State Army Maintenance Program.

2.5.3 Navigation ("A bird in the hand." 20 Oct 1999. 20 Apr 2001. http://idr.janes.com/samples/idr0506.html.)

Since Oiseau is a autonomous /semi autonomous aircraft it will rely heavily on its onboard avionics systems. The onboard flight computer will be able to access the onboard integrated avionics system, Center of Gravity Control Computer, and fly-by-wire control system, the computer is able to maintain control of aircraft at all time. This computer via secure wireless network interface is linked to A_GCS, Oiseau and spy_Oiseau. A Modular Integrated Avionics group will control flight controls, autopilot, navigation and sensor payload. (MIAG and MIAG IFF). The primary auxiliary systems carried aboard the aircraft are listed below.

Table 2Auxiliary on-board Systems ("ADF Employment of the Global Hawk Uninhabited Aerial Vehicle.")

Name	Weight(lb)	Dimensions(in)
Multi-Application Control Computer	8.11	10.15x17.63x10
Modular Integrated Avionics Group	4.87	5x5.5x5.6
VHF Data Link	5.0	3x6x8
Anti-jamming adaptive GPS antenna	1.0	6x0.5
Ultra 6000 FLIR	42.0	11x11x15
Fly-by-wire system	44.1	18x10x27
Center of Gravity Control Computer	8.2	2 MCU
Defensive Management Suite	40.0	

2.5.3.1 The Multi-Application Control Computer (MACC)

The MACC is monitored and controlled by A-GCS and is capable of processing the inputs from 50,000 sensor sets. The MACC is currently used in aircraft for flight control, vehicle management system control, and actuator/subsystem control.

2.5.3.2 The Modular Integrated Avionics Group/Navigation Sensor

MIAG is a small lightweight modular core avionics system for UAVs with integrated local air data specifically designed for use in UAV's. Baseline configuration includes attitude and heading reference system (AHRS) which consist of a fiber optic inertial measurement unit to assist in attitude and heading references. A embedded Global Positioning System and Differential Global Positioning System GPS/DGPS receiver for pre-programmed aircraft navigation as well as general aircraft position data. It contains embedded air data sensors with powerful and versatile interfaces to the UAVs subsystem. In addition, several air data pressure transducers supply the flight computer with necessary airspeeds and altitudes. The unit also contains an engine command and control system as well as a payload management system. The MIAG has a built in IFF (identification--friend or foe) system, which identification status, mode, reply code, altitude, range, azimuth data degarbing and defruiting circuitry, jamming and garble indication to the operator display,

2.5.3.3 The Harris VHF Data Link and adaptive DGPS Antenna

The Harris VHF Data Link and adaptive DGPS antenna were designed for military use in areas filled with hostile electronic environments. The antenna is the primary system used to feed date to the MIAG.

2.5.3.4 The Ultra 6000 Airborne Imager

The Ultra 6000 airborne imager provides final targeting, imaging, and man-in-loop flight control. The system uses a high resolution CCD camera with a 15:1 zoom and advanced focal plane array detector technology to deliver high resolution infrared images. The system is capable of detecting thermal differences of less than 0.03 degrees C and can penetrate darkness, fog, and foliage to identify people and targets. The entire system is self-cooled with a Sterling closed cycle cooler. To designate targets a laser designator is attached to the FLIR so that target can be acquired independently. The FLIR is located in the nose of the aircraft giving it the ability to see below and in front of the aircraft.

2.5.3.5 Fly-by-Wire System

The avionics suite operates the control surfaces and thrust vectoring via an analog fly-by-wire system. The FBW used on the aircraft is the same as that used on F-16 Fighting Falcon fighter.

2.5.3.6 The Center of Gravity Computer

The Center of Gravity Computer is included to assists the FBW in maintaining smooth, stable flight.

2.5.3.7 The AN/APR-50 Electronic Warfare System

The AN/APR-50 electronic warfare system is currently used on the B-2 Spirit. The system is capable of covering the lower frequencies and up to Band 4 from 500 MHz to 1 GHz. Very little information is available on this highly classified system. ("ADF Employment of the Global Hawk Uninhabited Aerial Vehicle.")

2.5.3.8 Concepts

2.5.3.8.1 Operational Concept: Minimum crew of one, during possible payload release is needed to take control of Oiseau from A-GCS for inputting pre-programmed navigation controls and to control the aircraft when necessary. ("ADF Employment of the Global Hawk Uninhabited Aerial Vehicle.")

2.5.3.8.2 Maintenance Concept: The maintenance concept for Spy-Oiseau and Oiseau follows the general direction and guidance provided by the United State Army Maintenance Program.

2.5.2 Sensors

Figure 2.5.2.1: Clockwise to top left: EO, MTI, IR, and SAR(16)

2.5.2.1 Reconnaissance Suite

This reconnaissance suite is based on the Global Hawk Integrated Sensor Suite(16). This modified reconnaissance suite of sensor detects, identifies, locates and reports on threats, including surface-to-air and antiaircraft batteries. The complete payload will utilizes Chip-On-Flex this shaves away excess weight from the package that isn't critical to operation of circuit.

Each major aircraft function, synthetic aperture radar, Moving target indication, and combined electro-optical/infra-red sensor will have its own 'tile" making future upgrading easier and aids in heat transfer during flight.

A reconnaissance suite linked to A-GCS via satellite, and spy_Oiseau comprises a high resolution synthetic aperture radar(SAR) and moving target indication(MTI) with combined electro-optical(EO)/infra-red sensor (IR). This combined sensor package includes a digital CCD camera. The five micron IR sensor based on AN/AAQ-16B helicopter system mounted under the nose with an I/J-band SAR just to the rear. The SAR can operate simultaneously with either EO or IR sensor, enabling wide-area search (WAS) for situational awareness and threat assessment, as well as a narrower focus on specific targets for prosecutions and battle damage indication. The integrated sensor package provides the capability to select radar, IR and visible wavelength imagery as required, and to use the radar simultaneously with either of the other two sensors.

2.5.2.2 SAR

Scanning from either side of the UAV, the gimbaled radar antenna obtains SAR imagery in spot mode and SAR imagery in WAS mode, using reliable, cost-effective commercial off-the shelf hardware and software.("Supermodels prepare for War." 26 Oct 1999. 20 Apr 2001.)

2.5.2.3 MTI

The MTI data provide information on enemy intent, including troop disposition and force repositioning.

2.5.2.4 EO/IR

The EO/IR system contain IR sensor and digital CCD visible camera. They provide imagery that allows users to distinguish types of vehicles, aircraft, and ships.

2.5.2.4 Specifications

Table 3Oiseau integrated sensor suite (ISSS)

Unit Name	Dimensions(in)	Volume(ft^3)	Weight(lb)
Receiver/exciter/controller	19x16x19	3.34	101
Integrated sensor processor	19x21x22.68	5.24	176
Transmitter	19x12.22x24	3.22	90
Sensor electronics Unit	19x13.69x16.5	2.48	63.52
Power distribution	14.4x5x19.5	.81	40
Antenna/gimbal	14.4x49.5	-	95
EO/IR receiver unit	24.5x26.19x42.29	15.70	271.3
WISS			885

2.5.2.4 Operational Status

Upgrade required:

Prime Contractor: Raytheon, Electronic Systems, El Segundo, California

Customer: US Air Force

Costs: Research and implementation funding required for enabling technology.

2.5.3.8 Concepts

2.5.3.8.1 Operational Concept: Minimum crew of one pilot, during possible payload release is needed to take control of Oiseau from A-GCS to input pre-programmed navigation controls and to control the aircraft when necessary. ("Supermodels prepare for War." 26 Oct 1999. 20 Apr 2001.)

2.5.3.8.2 Maintenance Concept: The maintenance concept for Spy-Oiseau and Oiseau follows the general direction and guidance provided by the United State Army Maintenance Program.

2.6 Control System

2.6.1 Ground Pilot

In order to steer the Oiseau, the speed of one track is reduced relative to that of other. The Oiseau will turn in the direction corresponding to the slower side of the vehicle. The speed of the two tracks is controlled in order to accelerate or decelerate the Oiseau. The torque is controlled to climb over obstacles. In the case that an obstacle is too large negotiate with the ground system, the Oiseau will go into flight mode.

2.6.2 Wing Pilot

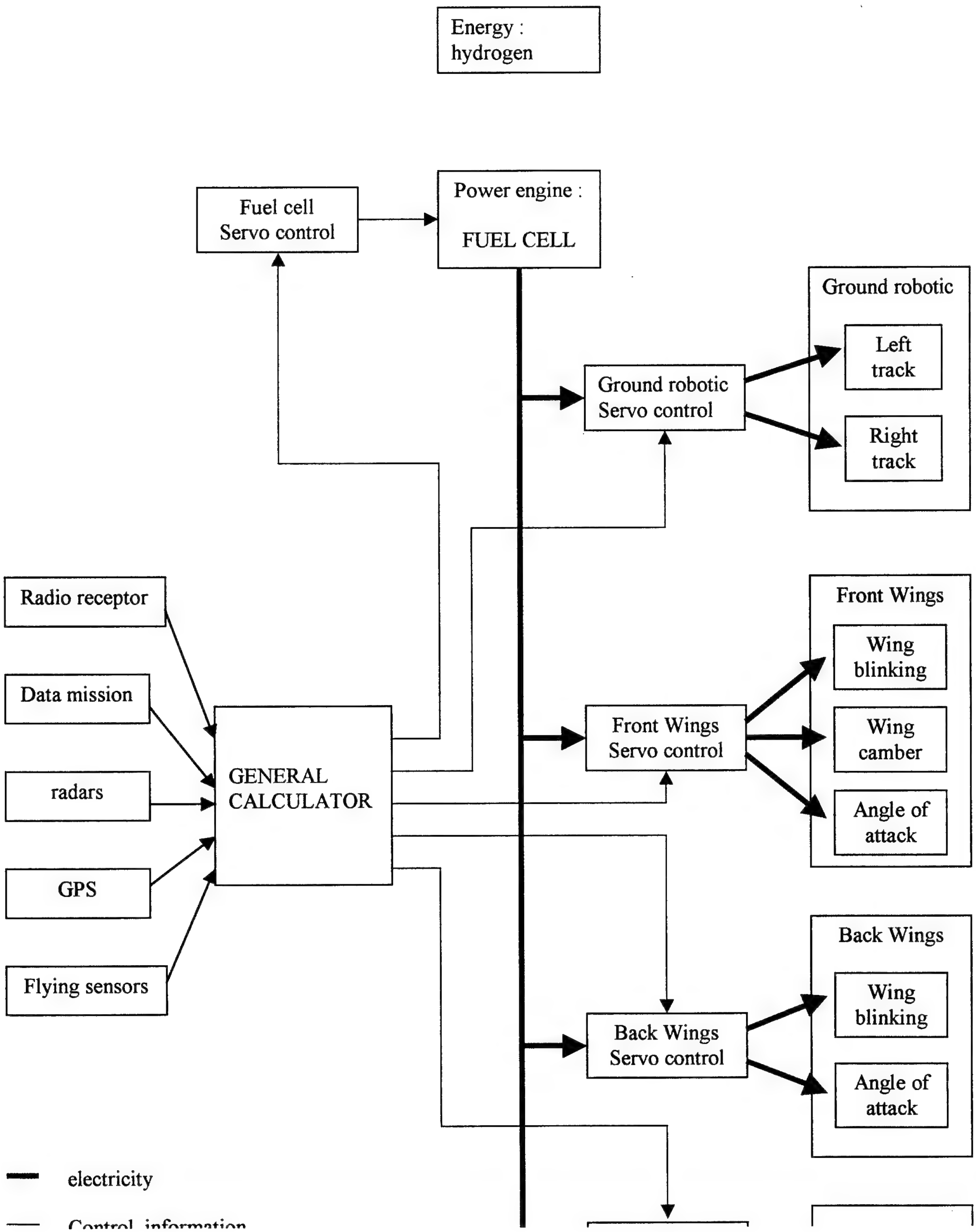
The wings will flap at a prescribed frequency based on the flight situation: take-off, cruise, landing, or hover. The angle of attack of each wing is controlled based on the flight profile. The camber of the front wings is controlled to modify the power sustentation during low speed flight.

During take off and hovering, all four wings will flap. In this case, the back wings will follow the same cycle as the front wings, but will flap at half a period off. During forward flight, the back wings will stop flapping. They will be controlled independently to assist in steering the Oiseau.

2.6.3 Command Diagram

The command diagram is shown below in Figure 15.

Figure 15



Energy : hydrogen
Fuel cell Servo control
Power engine : FUEL CELL
Ground robotic
Left track
Ground robotic Servo control
Right track
Radio receptor
Front Wings
Wing blinking
Data mission
Front Wings Servo control
Wing camber
radars
GENERAL CALCULATOR
Angle of attack
GPS
Back Wings
Flying sensors
Wing blinking
Back Wings Servo control
Angle of attack
electricity
Control information

2.8 Mechanical Configuration

2.8.1 Material Overview

The performance of the Oiseau is partly determined by the materials used in its construction. The materials needed are those that have excellent mechanical properties, while also being very lightweight. Also needed are "smart" materials, which are a rapidly developing class of materials that can react predictably, given inputs from a computer. These types of materials will allow the Oiseau to fly faster, be more agile in flight and survive the threats of tomorrow's battlefield. The choice of the primary materials and their benefit is shown in Table 4.

Table 4 Structural Components

Component	Material	Benefits
Frame	Magnesium Alloy (AZ31B)	Lightweight and strong
Outer Skin	Carbon/Epoxy CFS003	Large strength to weight ratio
Wing Frame	Titanium	Lightweight and strong
Wing Skin	Gore-Tex	Allows air to pass through in 1 direction
Wing Shaper	Pizeo-Electric	Quick and precise wing control
Track Material	Vinyl	Durable and inexpensive
Radar Absorbing Material	Polycrystalline Iron Fiber Radar Absorbing Material	Negligible weight, easy application, durable and inexpensive

2.8.2 Vehicle Configuration

The overall configuration of the Oiseau is one that allows the maximum flexibility and survivability in the field. The modular system employed allows for the soldier/technician in the field to make assessments and repairs in the field. The wings are detachable and can be exchanged for a new set upon mission completion from extra sets stored at the deployment site. The outer skin is easily removed from the body and allows access to the frame and internal components. The tracks for the ground robotics portion of the vehicle are changeable to allow for varying terrain types. The overall layout of internal components can be seen in Figure 13. Placement of the internal components is based upon the center of gravity of the vehicle to maintain stability. The payload is set along and below the center of gravity to allow it to be deployed at a drop-point without adverse effects to the stability of the Oiseau. Overall weight has been kept at a minimum to enhance the flight characteristics. Weight distribution can be seen in Figure 17.

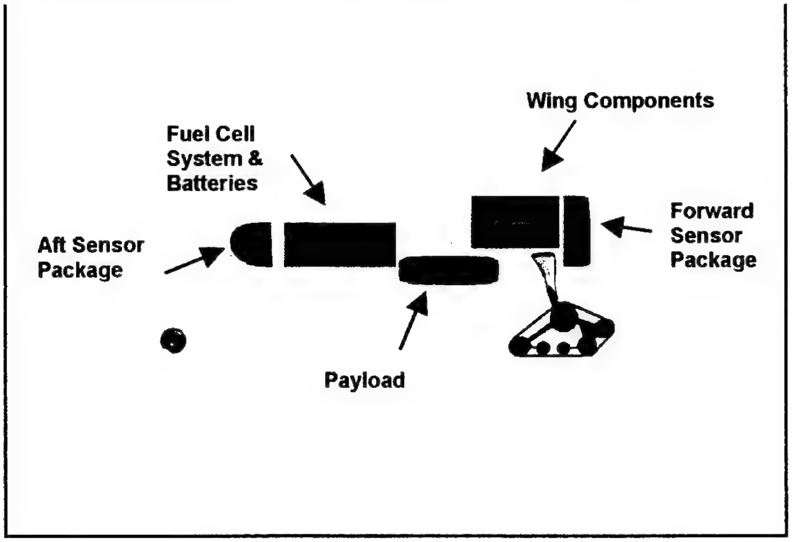


Figure 17

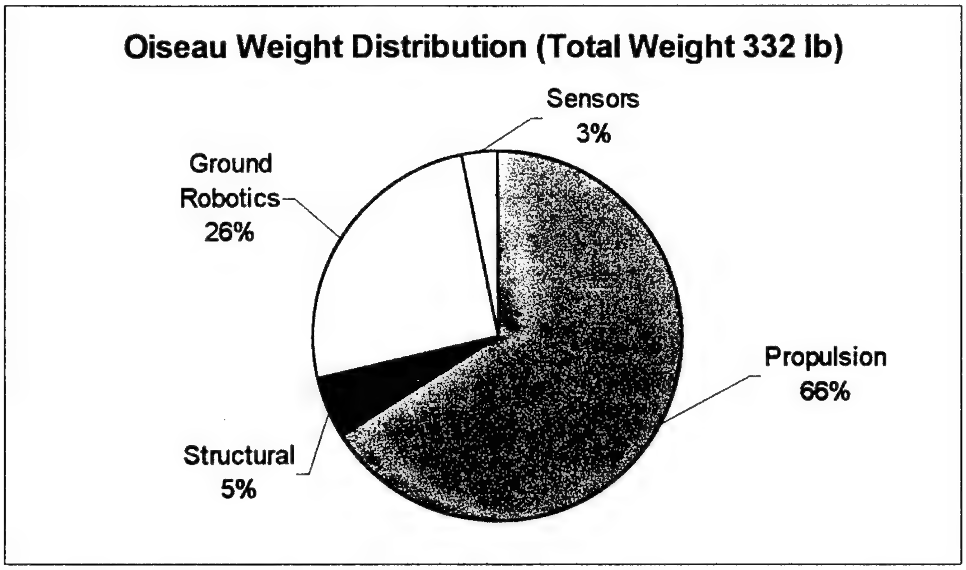


Figure 18

2.8.3 Enabling Technologies

The materials that have been chosen are based on an estimation of what will be available in the 20+ year time frame for use in a vehicle of this type. The juggling of cost with the material properties is always a challenge and has proved to be such in this project phase. The enabling technologies, not covered in other sections of this document, are the frame material, outer skin and the radar absorbing material.

The internal frame of the Oiseau uses Magnesium AZ31B. The frame is entirely made of 1-in. by 1-in. square tubing with a 1/16-in. wall thickness. The configuration chosen is a very strong box design with cross supports and stiffening bars at locations of high bending moments. This type of magnesium alloy was chosen because of its excellent strength to weight ratio. It has an ultimate strength of approximately 50 ksi, and a yield strength of 40 ksi. (Juvinall 2000) Its low density offers substantial weight savings over traditional frame

materials such as steel or even aluminum. This particular type of magnesium alloy is made for extruded shapes and is workable with a common TIG welder. Magnesium alloys have seen an increased amount of research in recent years in the overall push to lower vehicle weights. The United States Department of Energy has been supporting research efforts on this and many other materials through their Automotive Lightweight Materials Program. With new production techniques, magnesium alloy costs may be reduced to that of aluminum (Transportation for the 21st Century, Automotive Lightweight Materials Program Overview,U.S. Department of Energy, November 2000).

The skin employed for the Oiseau is a Carbon Fiber/Epoxy (CFS003/LTM25) composite. Possessing material properties of approximately 85 ksi in both longitudinal and transverse directions and in both tension and compression, it is a strong material weighing only 0.525 lb/in^3. (Berenberg4/18/01) Composite materials have been the focus of a large amount of research over the past few decades. Growth in United States shipments of composites has increased by over 13 times in the past 40 years (Fiber Reinforced Polymers – From Aerospace to Infrastructure, Australian Academy of Technological Sciences and Engineering, Dr. Robert Ian Mair, No. 107, May/June 1999). This trend, along with the more common usage of these types of materials in automobiles and aircraft, implies that costs will continue to decrease over time. As more research is done, this material may be able to be coupled with Kevlar or a metal matrix for small arms protection or even as the main load bearing structure itself.

The material chosen for the reduction of the radar cross signature is known by the trade name PIFRAM Electro Magnetic Radar Absorbing Material. It is currently used to enhance the radar absorbing capabilities of older systems. The next 35 years is supposed to see 2 or 3 major upgrades of this material if the company, AFIA Inc., is able to stay on schedule. Using a urethane rubber matrix, the material is of almost negligible weight and can be custom tailored to the potential radar systems that it might be seen by. It is able to be bonded to any shape surface and is ideally used in systems where lightweight and broadband performance is essential.(Naval-technology.com, AFIA Inc., Stealth, signature reduction materials, 4/9/01) Because of the sharp angles seen on the Oiseau, the ability of this material to significantly reduce the RCS of the vehicle is not known with the current level of analysis.

2.9 Technical Summary

The Oiseau is a unique proposal designed to fulfill a unique set of requirements. As has been stated in the previous sections, the Oiseau not only meets the specification, but it exceeds it in some respects. The preliminary calculations of power requirements yield 41KW for takeoff and vertical climb and 35KW for hover. The propulsion, accomplished by nearly silent electrical motors, yields a long potential range. The ground robotics are robust enough to handle any environment the Oiseau might encounter. With a ground speed of 10 km/hr it has world class performance for UGV's. The sensors and communications are complete enough to handle the demanding requirements set forth by the specification. Lastly, the mechanical configuration has been optimized for lightweight (17 lbs) and good strength. All of these factors combine to form a vehicle with a gross weight of 332 lbs and a payload of 60 lbs.

There are several critical problems that need to be addressed by the next design iteration. First, the natural frequency of the body structure and the wing structure should be calculated. These structures could experience short life and/or catastrophic failure is the flapping frequency is near the resonant frequency. Secondly, a mechanism should be integrated into the wing structure that enables them to fold into a more compact shape during ground travel. This is needed to retain not only functionality, but stealth ability while traversing ground. Lastly, a mechanism to provide for the stability of critical sensors needs to be developed. There will be vibration inherent in the structure while in flight; therefore, an active mechanical damping system is required to give the sensors a stable platform from which to operate.

Table 2. Concepts Technical Information

Comparison Criteria	**Proposed Concept**
Overall Specifications	
Air Configuration	Flapping Wings
Ground Configuration	Mattracks
Payload Mass, kg (lb)	68 lb
Gross Takeoff Weight. kg (lb)	332 lb
Energy Source for Air Transport	Fuel cells
Energy Source for Ground Transport	Fuel cells
Hovering Power, Kw (hp)	35 Kw(47 hp)
Cruise Power at 15 km/hr , Kw, (hp)	7.4 Kw
Total Energy for Mission Profile, KJ (BTU)	299,259 kJ (283,631 BTU)
Basis of Autonomy	MACC
Primary BLOS Method	"Spy Oiseau"
Primary Structural Material	Magnesium and Carbon Fiber
Enabling Technology 1	Fuel Cells and Electric Motors
Enabling Technology 2	Pizeoelectric Material
Enabling Technology 3	Wing Material
Enabling Technology 4	Chip on Flex Sensors
Structure	Magnesium Alloy and Carbon Fiber
Fuel Weight	1.6 lbs
Range	75 km

Figure 19- Cross Sectional Drawing

3.0 Implementation Issues

Whether the US Army decides to establish venture funding by teaming, pilot programs, or tax incentives to develop enabling technologies, Pegasus Engineering is in the position to take advantage of either scheme.

Since we are proposing a 20-year technology program to develop enabling technologies to field the AV/GV in 2025, we have several major issues. The primary issue is how to keep the US Army interested in a 20-year technology program. The second largest issue is picking and prioritizing the enabling technologies that will allow us to field the AV/GV in 2025.

We have structured our proposed program to provide major milestones every four years to coincide with the US presidential elections.

We have borrowed Technology Readiness Levels (TRLs) from NASA and they are shown in the following figure.

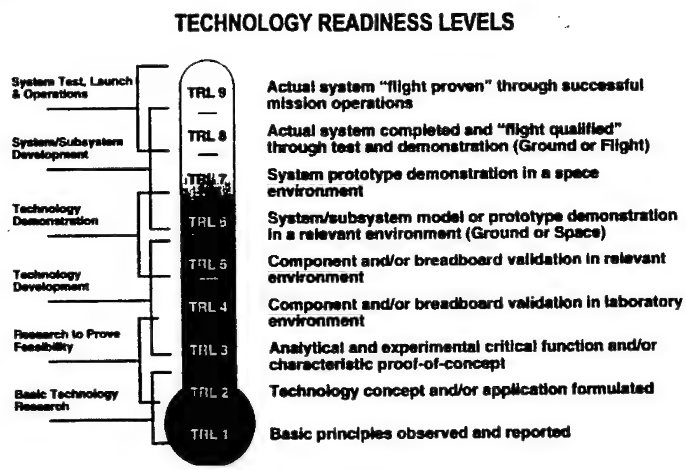


Figure 20 Technology Readiness Levels

The Analytic Hierarchy Process (AHP), which was employed by our team, determined the enabling technologies presented in this proposal and the set of candidate technology area investments. This technique attempts to counteract the bias that results from the interaction between group members in developing a group estimate. Each group member's opinion and rationale is obtained separately. These opinions and supporting reasons are then interpreted and categorized using the Churchman-Ackoff (Stewart 1995). The results are presented to each member for further evaluation and substantiation and the process is iterated until all major inconsistencies are eliminated. At this point, the analyst then calculates as set of median values from which the group estimate is determined.

We have selected the enabling technologies and prioritized them in the following list:

- Integrated Vehicle Health Management (IVHM) System
- Fuel Cells
- Piezoelectric Materials

Integrated Vehicle Health Management (IVHM) System

The status of current IVHM systems is as follows:

- Excessive scheduled and unscheduled maintenance time expended performing pre/post flight, troubling, and corrective maintenance actions
- Results in length turnaround times and high costs
- System health status is performed with labor-intensive inspections and corrective maintenance.
- Automated on board and ground health management system is required to reduce costs, increase reliability, and minimize turnaround time

The enabling technology goal for AV/GV IVHM system is to identify all failures in adequate time to implement corrective action:

- Technology Required
  - IVHM sensors
  - Intelligent hierarchical architecture
  - Prognostics
- Maintainability Assessment
  - Reduced turnaround time
  - IVHM maintenance concept and man hours
  - Fewer skill levels required
- Safety and Reliability Assessment
  - Improved fault isolation and intelligent management
  - Improved mission reliability due to informed health detection, assessment, prognostics, and fault isolation
  - Decrease in "could not duplicate and retest"
  - "Condition based" rather than scheduled maintenance
- Support System Impact
  - Less support equipment required
  - Fewer maintenance procedures required
  - Less training required
  - More accurate spares provisioning
  - Reduced cost per sortie
- Expected Benefits:
  - Reduced mass, cost, and risk
  - Cheaper and robust
  - Demonstrate enabling technologies
  - Leverages common capabilities
  - Synergize technology needs
  - Use flight demos to increase confidence in AV/GV
  - Develop and demo core technologies to minimize technical, schedule, and cost risks

Fuel Cells

The status of current fuel cells is as follows:

- Serious interest in fuel cells began in the 1960s, as part of the U.S. space program.

- Fuel cells have been demonstrated and are currently planned for use in several prototype personal vehicles. The automotive industry is investing significantly in the further development of fuel cells.
- Power output has increased by ten times over the last five years, and can be expected to improve.
- Hydrogen is not readily available. As a result, fuel cells are currently expensive. They cost about $3,000.00 per kilowatt.

The enabling technology goal for AV/GV fuel cells is to identify all failures in adequate time to implement corrective action. Our proposal to accomplish this goal is listed below:

- Technology Required
  - Hydrogen production

- Maintainability Assessment
  - No moving parts
  - The reaction is between hydrogen and oxygen, and is not damaging to the cell material.
  - The longest period a fuel cell has been run continuously is 9,500 hours.

- Safety and Reliability Assessment
  - Storage of hydrogen in a vehicle is safer than storage of gasoline. Each tank design must be qualified at 2.25 times the normal operating pressure.
  - Hydrogen has a lower flammability limit than gasoline because it will disperse more quickly.
  - The oldest fuel cell installation has been working for 40,000 hours.

- Support System Impact
  - Smaller motor as a result of improved efficiency

- Expected Benefits:
  - Reduced cost and mass
  - Improved Performance
  - Improved Safety
  - Quick Refueling and longer range
  - Increased efficiency

Piezoelectric Materials

The status of current piezoelectric materials is as follows:

- When a voltage is applied to piezoelectric material, its shape changes. Conversely, if a pressure is applied to a piezoelectric material a voltage is generated. Currently, the motion is limited.
- Piezoelectric materials are fairly expensive.

The enabling technology goal for AV/GV piezoelectric materials is to identify all failures in adequate time to implement corrective action. Our proposal to accomplish this goal is listed below:

- Technology Required
  - Actuators, or Sensors
  - Micro-electronics

- Maintainability Assessment
  - Combines strength and flexibility
  - Reduces moving parts and machining time
  -

- Support System Impact
  - Reduces weight
  - Eliminates need for large, heavy pivots in body

- Expected Benefits:
  - Reduced Cost
  - Lightweight, flexible structure
- Increased Maneuverability and Control

3.1 Programmatics Ground Rules and Assumptions

The assumed time frame of the AV/GV Program is as follows:

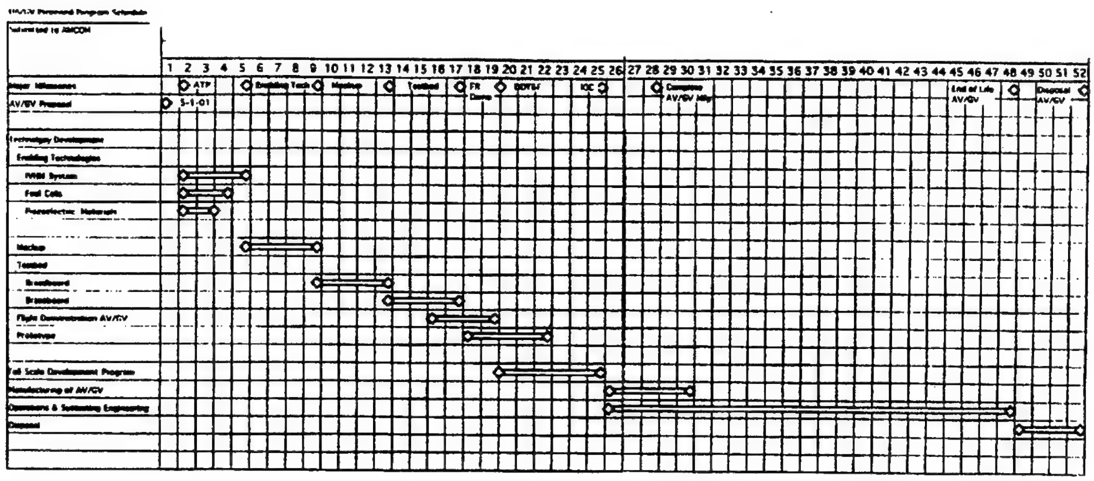
- Take advantage of US Army's initiative to fund enabling technologies
- We are a technology development company who will transition to a Full Scale Development and Manufacturing company by 2020
- Final Proposal is due April 24, 2001

3.2 Work Breakdown Structure (WBS)

The level 3 WBS is shown in the appendix.

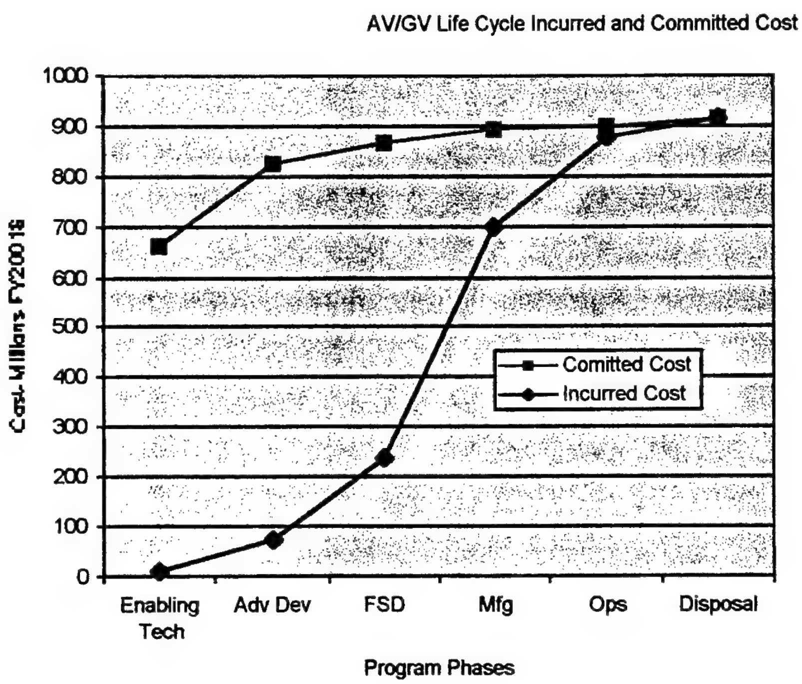
The AV/GV program is a technology program beginning October 1, 2001 through September 30, 2000. This time frame will be used to develop innovative enabling technologies to reduce the LCC cost, reduce the performance risks, and reduce the schedule risks. We will begin with the "high pay off" technologies as shown on the following life cycle schedule:

3.3 Life Cycle Schedule



3.4 Life Cycle Costs

The major milestones of the life cycle schedule and life cycle costs are arranged every four years to coincide with the USA presidential elections. The following chart compares the committed cost over the life cycle to the incurred cost over the life cycle



3.5 Risk Analysis

We have chosen Venture Evaluation and Review Technique (VERT), an automated computer program, to perform our technical, cost, and schedule risk analyses (Moeller 1979). Due to the large amount of manpower, lack of an up-to-date AV/GV database, we conducted a

simplified risk assessment while we build the required database. We are in the process of acquiring the necessary programmatics personnel, computerized tools, and acquiring the necessary training so that when we win this competition, we will be in position to perform a comprehensive technical, cost, schedule, and risk analysis with critical path analyses.

Today there are a wide variety of computerized risk analysis techniques available. We have chosen VERT a computerized technical, cost, schedule, and risk analysis to conduct the following assessments in greater depth:

- Risk assessment of the decision to undertake AV/GV program
- Risk assessment of AV/GV project alternatives
- Risk assessment of AV/GV technical, schedule, and costs

Cost risk analysis techniques normally do not address risk from a program structure but from a cost estimating structure, and consider the risk associated with the development of the individual cost elements. However we are going to use VERT which requires a high degree of management input relative to goals, objectives and critical decisions which greatly increased resources (manpower, computer software, and training over an extended time period) required to conduct the necessary performance, schedule and cost risk analyses.

- Assessment of alternatives for risk reduction

Technical performance risk of the AV/GV also affects the cost and schedule risk. An in-depth analysis provides risk assessment of all three areas resulting in an identification of the interrelationship of these variables and the associated uncertainties. It provides extensive information about project uncertainty and provides a tracking system for the AV/GV program manager to use in evaluating the project performance.

3.5.1 Technical Performance

Complex Research & Development projects such as AV/GV benefit from advanced network analysis or decision risk analysis techniques. One primary advantage of network analysis techniques such as VERT is the ability to be used as project tracking tools. VERT has the capability to build a baseline cost estimate using skill levels and contract identification codes that provide the capability of tracking a project by comparing actual time, cost, and technical performance to those estimated. The network can then be revised periodically to reflect remaining project risk.

Because VERT includes technical performance, "what if" exercises can be performed to define the best approach to provide the shortest schedule, the least cost, and the highest technical performance or a combination of the three.

VERT is a powerful network analysis tool, but requires a high level of skill to develop, analyze, and use. Because the AV/GV required data does not currently exist in a comprehensive database, we must expend a large amount of time in creating the necessary AV/GV database.

3.5.2 Schedule

We are proposing to use VERT, a very powerful computerized network tool, which requires a high level of skill to develop, analyze, and use the network along with a comprehensive database.

In the cost estimating risk analysis technique, cost uncertainty is addressed from a cost estimating perspective. Therefore cost estimating risk analysis techniques require that the cost estimating of the program be established. Once a program cost estimate has been developed, then the uncertainty associated with the estimate can be assessed. However. We propose to use VERT, a decision risk analysis technique where uncertainty is primarily affected by critical decision. This type of risk analysis is best used when risk is orientated toward goals and objectives and addresses the problem that occurs given a particular decision. VERT also requires a high degree of management input relative to goals, objectives and critical decisions which greatly increases the resources required to conduct technical, schedule, and cost risk analyses.

3.5.3 Cost

We are proposing a program to develop a 20-year enabling technology program for AV/GV project followed by a five-year full-scale development program. The major thrust of our proposal is aimed at the enabling technology program. As a new start up company, we will positioned to bid for the Full Scale Development of AV/GV after successfully completing the proposed 20 year enabling technology program. Our propose Program Manager, Ms. Melanie Janetka is currently in her early 20's which will put her in her early 40's when Full Scale Development of the AV/GV begins with 20 year of successful experience in developing the AV/GV enabling technologies. A young and able staff who is ready to begin development of the enabling technologies for the AV/GV October 1, 2001 supports Ms. Janetka.

We have working relationships with DOD and NASA technologist. As we approach 2020, we will transition from a technology development house into a Full Scale Development and Manufacturing house by acquisitions.

3.6 Discussion of Application and Feasibility

We believe that our proposed program will provide the US Army a viable, reliable, and affordable AV/GV with an IOC of 2025.

4.0 Company Capabilities

4.1 Company Overview

Pegasus Engineering is a recently formed, multi-disciplinary team of engineers based in Huntsville, Alabama. With team members from France, United Arab Emirates, India and

various parts of the United States, the company has a diversity of work experience as well as field expertise. By pooling together talented people with innovative ideas, Pegasus has proven its ability to deliver cutting edge technology backed by solid engineering concepts. This has been accomplished in a variety of ways.

First, Pegasus Engineering is not burdened with the management overhead that can hinder productivity. Good communication between the team leader and the rest of the team reduces the need for status meetings. This allows everyone on the team to contribute to the project in his or her various disciplines. Discipline teams meet together in informal settings that allow the members to brainstorm, debate concepts and solve problems together. The multi-discipline structure, which places each team member in both primary and secondary discipline groups, encourages a sense of unity by allowing a "global" view of where the project is heading. Individual strengths are optimized by allowing team members with particular interests or strengths to contribute information/data when opportunities permit.

Second, a broad based team enables all aspects of the project to be covered, not just the engineering portions. Pegasus utilizes team members with experience in aerodynamics, materials, programmatics, customer interaction, modeling, simulation, research and development programs, technical writing, manufacturing, and military contracts. Broad based teaming yields a well-balanced and capable group.

Third, the ability to gather information from sources outside the traditional methods have allowed the Pegasus members to incorporate into the project technologies not currently available or even known to a great majority of the public. This information has been collected by interacting with major industrial companies, government agencies, mentors, company websites, current textbooks and magazines. With the team leader, Melanie Janetka, as the primary interface with the customer, the Army's needs were well defined and understood. Technology and programmatic concerns were addressed with mentors, professionals and faculty from various universities.

4.2 Personnel Description

- Ms. Melanie Janetka – Pegasus Engineering Project Leader
  Ms. Janetka has shown excellent leadership qualities during the course of the program. Her unfailing ability to keep the discipline groups focused on the project allowed Pegasus to meet all deadlines with ease.

- Mr. Ben Bramblett – Pegasus Engineering Systems Integration/Spec Compliance Leader
  Mr. Bramblett has shown his ample ability to support almost every discipline during this project. By moving between the groups and performing research, he not only helped with technology assessment, but helped ensure that everyone was meeting the specification.

- Mr. Chris Hirstein - Pegasus Engineering Aerodynamics Team Leader
  Mr. Hirstein was instrumental in the development of the airfoil model used in this project. As a senior in Mechanical and Aerospace Engineering progam, he showed his

capabilities as he worked tirelessly to understand and formulate one of the most critical aspects of the design.

- Mr. Shane Lackey - Pegasus Engineering Aerodynamics/Programatics Team
  With his experience in aerospace programs involving different flight systems, Mr. Lackey was able to move into the aerodynamics analysis of the concept with ease. His ablility to gather information from business contacts allowed the team to gain valuable insight on the equation set used.

- Mr. Tim Weaver - Pegasus Engineering Aerodynamics/Propulsion Team
  Mr. Weaver is a unique individual with unique talents. As a member of two teams, he showed an excitement for the technologies he was studying as he focused his efforts on some of the more critical calculations.

- Mr. Rajat Sharma - Pegasus Engineering Ground Robotics Lead/Mechanical Team
  Mr. Sharma has shown an uncanny ability to find data on the internet. Much of the technology obtained from that source came from his many hours of efforts. As our RCM expert, he interfaced with the inventor and obtained valuable information. Additionally, he headed up the Ground Robotics Team and worked as a liason with his French teammates.

- Mr. Demetrius Peoples - Pegasus Engineering Programmatics Lead
  Because of the complexity and breadth of his task, Mr. Peoples devoted his time entirely to the programatics development. He showed a superb ability to interact with his mentors and utilize that knowledge to form our developmental strategy.

- Ms. Linda Taylor - Pegasus Engineering Sensors Lead/Technical Writing Team
  Ms. Taylor used her Electical Engineering knowledge to lead the development of the sensors and communications for the UAGV. During the White Paper review, she demonstrated her knowledge of current and future systems by easily answering all of the questions put forward by the evaluators.

- Mr. Khalid Zarouni - Pegasus Engineering Sensors and Communications Team
  Mr. Zarouni used his extensive abilities in Electrical Engineering to help develop the communication and sensors platform used on the concept.

- Ms. Ségolène Brantschen - Pegasus Engineering Propulsion Team/ ESTACA Contact
  Ms. Brantschen was our ESTACA contact for the duration of the project. Her extensive reasearch and analysis of propulsion systems enabled us to make an informed decision.

- Mr. Cédric Trophardy - Pegasus Engineering Ground Robotics and Drive Team
  Mr. Trophardy contributed to our project through his work on the Ground Robotics and Drive Team.

- Mr. Cédric Van Essen - Pegasus Engineering Ground Robotics and Drive Team

Mr. Van Essen headed up the simulation portion of the Ground Robotics Team. With his knowledge of ADAMS software, he developed a cinematic rendering of the ground robotics in action.

- Mr. Nicolas Vergneault - Pegasus Engineering Propulsion Team
  Mr. Vergneault contributed to our project through his work on the Propulsion Team.

- Mr. Damon Hay - Pegasus Engineering Mechanical Configuration Team
  Using his experience as a machinist and his studies in Mechanical Engineering, Mr. Hay researched materials for the Mechanical Configuration Team. He was instrumental in obtaining key information on one of the visual sensors used by the UAGV.

- Mr. Jon Kilpatrick - Pegasus Engineering Mechanical Leader/ Technical Writing Team
  Mr. Kilpatrick used his experience in Mechanical Engineering to lead the Mechanical Configuration team. Using his experience in modeling, he developed a 3D model of the UAGV.

5.0 Summary and Conclusions

Future military operations require that forward reconnaissance missions be performed by automated vehicles that can perform under many conditions. These vehicles must possess stealth properties and an intelligence capability that is not now presently available. Pegasus Engineering has gone to great lengths to evaluate current and emerging technologies to determine the best combination available to meet the Army's requirements.

The novel concept of flapping flight may be new to the research institutes referenced, but it is readily present in nature. The Oiseau uses flapping technology because it offers solid performance at a relatively high efficiency, just like nature. Flapping offers the advantage of being able to move at many speeds as well as hover. Smart materials, such as piezoelectrically deformed wings, radar absorbing materials and active camouflage offer agility and stealth to the vehicle. Fuel cells offer quiet propulsion and a readily supply of fuel in the form of hydrogen, which can be stored with the deployment vehicle. This UAV/UGV offers ease of maintenance while in the field because of its modular make-up and even comes supplied with extra components to keep it in service and in support of our military forces longer. The Oiseau meets the specification in every category and is an excellent candidate for future development.

6.0 Recommendations

The technologies presented in this paper are moving forward, but are still not fully developed. One recommendation is that flapping wing analyses of vehicles, in larger scales than the micro-UAV's, be conducted. It is also recommended that a greater than first order approximation of the performance characteristics be carried out to determine the wing loading, stress concentrations, frequency response, frequency effects and optimal wing shaping during the flapping motion. Current tip to tip wing length is 16 ft. New processing

techniques and materials are needed to produce a lighter and smaller vehicle. Finally, more research needs to be done in the communications and artificial intelligence fields to make a truly autonomous vehicle that can operate in any condition.

References

"A bird in the hand." 20 Oct 1999. 20 Apr 2001. http://idr.janes.com/samples/idr0506.html

"ADF Employment of the Global Hawk Uninhabited Aerial Vehicle."

Arthur D. Little, *PEM Fuel Cell Technology for Transportation Applications: Status and Prospects*, 1996.

Bezian, Jean Jacques, Centre d'Energetique de l'Ecole des Mines de Paris. Systemes de piles a combustible pour la cogénération. October 31,1998.

Chronister, Nathan. Flapping Flight-How Birds Fly. http://www.catskill.net/evolution/flight/birdsfly/birdsfly.html. Accessed: March 13, 2001.

Composite Materials, Barry Berenberg, About.com website, Carbon/Graphite Database-Composite Materials, 4/18/01

Dryden, Richard. Bird Flight-Adaptive Airfoils. http://www.nurseminerva.co.uk/adapt/bird.htm. Accessed: March 14, 2001

Fiber Reinforced Polymers – From Aerospace to Infrastructure, Australian Academy of Technological Sciences and Engineering, Dr. Robert Ian Mair, No. 107, May/June 1999

Fundamentals of Machine Component Design, Appendix C-14, pg. 859, 3rd Edition, Juvinall, Robert and Marshek, Kurt, John Wiley & Sons, Inc., 2000

http://technology.ksc.nasa.gov/wwwaccess/techreports/97/07-EI/ei07.html accessed 10 April 2001

http:// www.fuelcells.org . Accessed April 10, 2001.

http:// www.blador.com/information . Accessed April 14, 2001.

Jones, K.D., Lai, J.C.S., Tuncer, I.H. and Platzer, M.F., "Computational and Experimental Investigation of Flapping-Foil Propulsion," 1st International Symposium on Aqua Bio-Mechanisms / International Seminar on Aqua Bio-Mechanisms, Tokai University Pacific Center, Honolulu, Hawaii, August 27-30 2000.

Kuethe, Arnold M. and Chow, Chen-Yen. 1998. "Foundations of Aerodynamics-Bases of Aerodynamic Design", John Wiley & Sons.

Moeller, G.L., *Venture Evaluation and Review Technique,* Decision Models Directorate, US Army Armament Material Readiness Command, Rock Island, IL, Nov. 1979.

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The Natural History Museum of Los Angeles County Foundation. The Bird Site-Flight. http://www.nhm.org/birds/guide/pg018.html. Accessed: March 14, 2001

Naval-technology.com, AFIA Inc., Stealth, signature reduction materials, 4/9/01

Stewart, Rodney. Cost Estimator's Reference Manual. John Wiley & Sons, 1995.

"Supermodels prepare for War." 26 Oct 1999. 20 Apr 2001. http://www.janes.com/press/pc991026.shtml

Transportation for the 21st Century, Automotive Lightweight Materials Program Overview,U.S. Department of Energy, November 2000

"UCAVs & MAVs", 01 Feb 2001. 20 Apr 2001. http://vectorsite.tripod.com/avuavc.html

White, Frank M. 1999. "Fluid Mechanics", John Wiley & Sons

Appendix A - Concept Description Document

1. General Description of Operational Capability
   1.1. Overall Mission Area
      1.1.1. The system shall be a versatile scout and pack animal for future force structures.
      1.1.2. The system shall be capable for use for area/target reconnoitering.
      1.1.3. The system shall be capable for use in terrain definition.
      1.1.4. The system shall be capable for use in situational awareness.
      1.1.5. The system shall be capable of both autonomous and semi-autonomous operation.
         1.1.5.1. The system shall be capable of human interface as required.
      1.1.6. The system shall be capable of executing both a preplanned and an alter mission profile.
      1.1.7. The system shall be capable of navigating and functioning without a payload.
   1.2. Operational Concept
      1.2.1. The system shall be capable of operation in a nap of the earth configuration.
      1.2.2. The system shall be capable of operation at a range of 15-30 km from the launch point.
         1.2.2.1. The system shall be capable of gathering information on threat activities at range.
         1.2.2.2. The system shall be capable of enhancing the RSTA/BDA.
         1.2.2.3. The system shall be capable of transmitting information via secure data links and C2 structures BLOS.
         1.2.2.4. The system shall be capable of using TF/TA hardware and software to define and navigate complex terrain.
         1.2.2.5. The system may encompass a degree of AI, ATR, and on-board decision making.
      1.2.3. Payload Requirements
         1.2.3.1. The system shall be capable of carrying a payload of 60lbs required gross weight, 120lbs desired gross weight.
         1.2.3.2. The system shall be capable of moving the payload to operational range in 30 minutes or less and be able to return from range in 30 minutes or less.
            1.2.3.2.1. The vehicle will have a minimum cruise speed of 30 km/hr and a desired speed of 100 km/hr.
      1.2.4. Mission Requirements
         1.2.4.1. The system shall be capable of landing in an unprepared area
            1.2.4.1.1. The vehicle must have vertical takeoff and landing capabilities.
         1.2.4.3. The system shall maximize survivability.
            1.2.4.3.1. The system shall be capable of avoiding sonic detection.
            1.2.4.3.2. The system shall have a near quiet acoustic signature.
            1.2.4.3.3. The system shall be designed for an operational altitude of 0 – 500 ft AGL.
            1.2.4.3.4. The system must have a 250 fpm VROC, 500 fpm desired.
         1.2.4.4. The system must have a flight profile of hover to full flight.

IPT _:

2. System Capabilities
    2.1. The system shall be capable of operation at an altitude of 4000ft, 95 degrees Fahrenheit ambient temperature, and not using more than 95% intermediate rated power (IRP).
    2.2. Operational Performance
        2.2.1. The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse environmental conditions worldwide.
        2.2.2 The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse geographical conditions worldwide.
        2.2.3. The system shall be capable of operating from any unimproved land or sea borne facility surface day or night, including low illumination.
        2.2.4. The system shall be capable of operation under battlefield obscurants.
    2.3. The system shall possess the following electronic capabilities:
        2.3.1. Mission Planning System
            2.3.1.1. The system shall possess a point-and-click pre-mission planning system to simulate mission flight.
            2.3.1.2. The system shall possess data loading capabilities.
            2.3.1.3. The system shall be capable of coordination and reaction to immediate operational mission changes.
            2.3.1.4. The system shall be capable of processing self-awareness and threat sensor inputs.
            2.3.1.5. The system shall be capable of enabling TF/TA from digital mapping information from satellite or other sources.
        2.3.2. Avionics
            2.3.2.1. Communications and navigation suite architecture shall be compatible with emerging JCDL and/or JAUGS.
            2.3.2.2. Payload must be "plug and play."
        2.3.3. Communications
            2.3.3.1. System communications shall be robust and have clear secure modes of operation
            2.3.3.2. Communications shall be simultaneously LOS and BLOS which can include satellite relay or other relay system compatibility.
            2.3.3.3. System must posses IFF and be compliant to all FCC/military communication regulations.
            2.3.3.4. System must be capable of communication with and sharing digital mapping/targeting information with other DoD RSTA platforms.
        2.3.4. Connectivity
            2.3.4.1. The system shall be interoperable with other DoD systems envisioned for the 2025 battlefield to the maximum extent possible and be compatible with service unique C41 systems.

Appendix B - White Paper

Alternate Concepts White Paper

IPT 2

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Abstract

The nature of warfare has changed. Emerging world powers and warring factions have hastened the development of smaller and faster military units to deal with conflicts anywhere in the world. A new generation of "intelligent" robotic systems are needed to help soldiers in the field assess situations with both accuracy and stealth. To fill this need, Pegasus Engineering has developed four concepts that bridge the gap between Unmanned Aerial Vehicles (UAV) and Unmanned Ground Vehicles (UGV) by merging them into an autonomous and intelligent UAV/UGV system. The first concept uses current technology to mate a standard rotorcraft design with a ground robotic vehicle. It was found to be adequate now but not stealthy enough for the future. The second design uses the lift capability of a helium airship and the ground capabilities of a hovercraft. Lack of agility in the air and overall size keep this concept from being as viable as others in this paper. The third concept is concept is a modified autogyro (air) and track (ground) system which provides efficient flight characteristics, as well as excellent terrain negotiation while on the ground. The final concept is for a nature-inspired design, which uses rapidly flapping wings to generate lift and a wheeled system on the ground. While the theory of insect-like movement is intriguing, this technology will possibly entail a great amount of research to develop. The design that has been selected is the flapping wing concept.

Résumé

La nature de la guerre a changé. L'émergence de nouvelles puissances mondiales et de factions belligérantes ont poussé au développement d'unités militaires plus petites et plus rapides de façon à s'adapter à tous les conflits n'importe où dans le monde. Une nouvelle génération de systèmes robotisés intelligents est nécessaire pour aider les soldats à l'évaluation de la situation du champ de bataille avec à la fois précision et furtivité. Pour satisfaire ce besoin, Pegasus Engineering a développé 4 concepts qui font la liaison entre UAV et UGV, en les combinant dans un système UAV/UGV intelligent et autonome. Le premier concept utilise une technologie actuelle pour combiner un rotor standard avec un véhicule terrestre robotisé. Il a été évalué comme étant adéquat pour notre époque mais pas assez furtif pour le futur. Le second concept utilise la capacité de vol d'un ballon gonflé à l'hélium avec les capacités au sol d'un aéroglisseur. Le manque d'agilité dans les airs et sa grande dimension limitent la possibilité pour ce concept de devenir réalité. Le troisième concept est un ornothoptère qui utilise le battement rapide d'ailes pour générer la portance et une configuration à roues au sol. Comme la technologie du mouvement du vol des insectes est novatrice, celle-ci nécessitera peut-être des coûts importants de développement. Le dernier et privilegié concept est un autogyre modifié avec un système chenillé qui procure de bonnes caractéristiques de vol de même

qu'une excellente adaptation au terrain pour la partie terrestre. Ce concept satisfait à l'ensemble des exigences requises dans les spécifications clients.

Technical Description

1.0 Overview of Phase 2

The Unmanned Air/Ground Vehicle (UAGV) sought by the U.S. Advanced Systems Directorate in envisioned to provide essential scouting and target recognition to the Brigade Commander. A Concept Description Document (CDD) finalizing the customer requirements for this system was endorsed by the customer and all participating teams on February 6, 2001. Phase 1 of the project produced one baseline concept that attempted to satisfy the project (CDD) using existing technology. During Phase 2, Pegasus Engineering at the University of Alabama in Huntsville has focused on synthesizing three alternative concepts. This White Paper provides a summary of the Baseline and our three alternative concepts. One of the concepts is selected for further development in Phase 3.

1.1 Specification Summary

The vehicle must be capable of vertical take off and landing. VTOL capabilities are necessary because the mission may require landing in an unprepared area. The vehicle must be able to take off vertically after completing the mission. The "unprepared area" could be a remote location with any type of terrain or a city that has been bombed.

The vehicle must be capable of carrying a 60 lb payload. A payload weight of 120 lb is desired. No details are specified for the payload regarding size, shape, or other information.

In order to maintain the operational tempo anticipated for future Army forces, the vehicle must be able to travel 15-30 km from the launch point in 30 minutes or less, while in flight mode. The UAV/UGV must be capable of remaining on station for 60 minutes, either hovering or maneuvering on the ground as dictated by the particular mission. The vehicle must also be able to return from range in 30 minutes.

For reasons of survivability, the UAV/UGV will follow a nap of the earth flight profile. In order to accomplish this, the vehicle must have a VROC of 250 fpm. A VROC of 500 fpm is desired. The operational altitude is 0-500 ft AGL.

Both autonomous and semi-autonomous operation is required. The UAV/UGV will include artificial intelligence. The vehicle will execute a preplanned mission profile, using on-board decision-making capabilities to negotiate obstacles. When certain decisions must be made, the UAV/UGV will alert the control station and wait for user input before proceeding. The vehicle will be able to communicate beyond the line of sight.

1.2 Key Challenges

Development of a hybrid UAV/UGV concept is an interesting and challenging problem in two respects; it requires unconventional thought and a technically feasible solution. Currently, several UAVs and UGVs are used by the U.S. military. However, no unmanned system exists that will perform the necessary air and ground maneuvers. In designing a hybrid vehicle, we are forced to think "out-of-the-box" to imagine a configuration, which

will satisfy the needs of the future Army, not the current forces. Regard technical issues, a hybrid vehicle that performs all of the reconnaissance functions would not be very difficult with current technology. Unfortunately, when the requirement of carrying a 60 lb payload is added, the design becomes significantly more complicated. In order to carry the necessary weight and maintain the performance characteristics, the vehicle must be fairly large. Resulting problems include a relatively loud acoustic signature, which is bad for survivability and equipment handling difficulties.

2.0 Description of Concepts

Our approach to designing a UAV/UGV concept began with an evaluation on current technology. In order to determine the limitations and weaknesses of a current system, we developed a baseline concept using only current technology and compared its performance characteristics to the customer requirements. Based on this comparison, a first-cut of three additional concepts were developed. Our strategies in choosing the three concepts were to research potential future technologies and incorporate them into three completely different systems. Our three concepts include a lighter-than-air vehicle, a modified autogyro, and a flapping wings vehicle. By developing concepts that are very different from each other, we were able to do a preliminary evaluation and choose the most promising concept. In the next phase of this project, the selected concept can then be adjusted and tailored.

2.1 Concept 2A "Pawnee"

This first concept is the baseline design, using only current technology (see figure 1). This was done to determine the state of modern technology and to see where improvements need to be made. The specifications state that the vehicle is to be ready to launch in approximately twenty-five years. This means that the selected system needs to utilize technology that has not yet been developed. To see where developments can be the most effect, the baseline uses only technology that is readily available and has already been proven to work and be effective. These technologies can then easily be compared to other systems that are currently being investigated or even developed. These new technologies are then integrated into the three alternate concepts selected by Pegasus Engineering.

The first concept is a conventional type rotorcraft (see figure 1). The design was done under the assumption of using currently available technology. Using counter-rotating blades, vertical takeoff and landing as well as flight control are accomplished without the use of a tail rotor. The blades are powered using a diesel cycle combustion engine. The engine chosen is produced by D-Star Engineering and is designed specifically for unmanned air vehicles. Some of the performance characteristics of the engine are 1.25 pounds of engine weight per horsepower and a specific fuel consumption of 0.40 lb/bhp-hr. The drive train for the vehicle will feature a transmission that is capable of switching power to either air or ground systems - eliminating the need for multiple power sources. The ground mobility is accomplished using four wheels and accompanying suspension and drive train components. The structure will feature a titanium frame with a carbon fiber outer "skin". The titanium was selected for its strength to weight ratio as was the carbon fiber. The communication package includes C band and L band transmission bands. The navigation system and associated sensors will feature GPS and inertial guidance and LIDAR for obstacle detection.

There are several advantages that this design has over other potential concepts. The technology exists and is proven. The aerodynamics and propulsion systems have been

produced before and have been employed by former Soviet aircraft such as the "Helix". The engine, ground robotic components, sensors, and communications systems already exist. The vehicle will use JP-8 as fuel. This is important because there is already infrastructure within the army for the handling the fuel. The only development needed is for a transfer case to switch power from the rotors to the ground systems after the unit has landed. The design also fulfills almost all of the requirements put forth by the specification.

There are also several disadvantages as well. First is the weight. According to estimates, the vehicle will weigh approximately 600 pounds. Although not a part of the specification, the vehicle weight is critical because the army desires a piece of equipment that can be manhandled by a small number of soldiers. Another disadvantage is that it will be very loud. One of the requirements is that the design has a low acoustic signature (which will clearly be violated). Unless an active noise dampening system can be developed, there is little that can be done about it.

2.2 Concept 2B "Blowfish"

The design for the second concept is a lighter than air vehicle (see figure 2). An inflatable balloon filled with helium will provide lift. Helium was chosen because it is incombustible (unlike hydrogen) and is readily available through commercial sources. Small ducted fans on either side of the vehicle will allow the ship to pitch and yaw. These fans can also be rotated to assist in the vertical takeoff and landing so that less helium is required. The fans will be powered by electric motors. Fuel cells will provide the electrical power. The movement along the ground will be controlled by a hovercraft system where the vehicle will ride on a cushion of air produced by and internal fan (also powered by an electric motor). The hovercraft will be able to traverse water and marsh as well as land. The two side fans will control the forward movement of the vehicle while it is on the ground. The vehicle will feature navigation, sensors, and communications equipment similar to the baseline design.

There are several advantages that this concept has over more conventional designs. First of all, the vehicle will be nearly silent. Any noise that is produced will be from the fan blades themselves. Also, because a fuel cell will be used to produce electricity, there will be virtually no heat signature, allowing the Blowfish to remain almost undetectable to the enemy. Another advantage is that the craft will be quick and agile while on the ground because of the near zero net weight of the vehicle. In the event that the flight balloon was to be punctured during battle, the helium would slowly leak out but would be able to return to the launch point. This is due to the fact that the pressure of the helium inside of the envelope is only slightly higher than that of the surrounding atmosphere. The hovercraft envelope will be reinforced to prevent any possible puncture while on the ground. In the event that the envelope is punctured or torn, smaller envelopes on the inside will be positioned so that the craft can make an emergency maneuver to evade the enemy (Neoteric Hovercraft 2001).

There are several disadvantages associated with this design however. First, and most obvious, is that the size of the balloon needed will be very large relative to the size of other concepts forwarded (Adaptive Aerofoils Feb 8, 2001). There are significant operational problems with this because of stealth and survivability issues. Helium and hydrogen, for this case, would take up almost the same amount of volume so there would be no advantage to using one over the other in the size aspect of the vehicle. Another disadvantage is that the maneuverability of lighter than air vehicles is less than optimal. This also implies operational survivability issues. The vehicle will have a hard time following the "Nap of the Earth" profile as set forth in the specifications. Yet another disadvantage is that infrastructure will have to be added to handle the helium in the lifting balloon. There are also additional problems with the hovercraft. If air gets under the front of the air cushion (i.e. the vehicle tries to go up a sudden slope change), the vehicle will tend to pitch nose up and move backwards causing a loss of control.

2.3 Concept 2C "Choctaw"

The third concept selected is a modified autogyro (see figure 3). For vertical takeoff, a rotor on top of the vehicle is run to a specified angular velocity range and at the instant of takeoff, power to the rotor is disconnected to eliminate any torque problems during flight (Brie 1934). A propeller on the rear of the vehicle provides forward motion through the air. This forward movement causes air to pass over the rotor blades on the top of the vehicle which then rotate and produce lift to allow the vehicle to stay in the air (CarterCopters Inc 2001). While on the ground, the system is carried on miniature tracks similar to those on a tank. One track on each side will provide forward motion as well as turn the vehicle. A small caster wheel in the front of the vehicle will turn freely similar to that on the front of a shopping cart. The visual sensor will be a panoramic camera with a 360° view of the battlefield. The communications and navigation systems will be similar to the baseline design.

The advantages to a system like this one are substantial. The ability to use the power from the engine to turn a pusher propeller instead of a traditional helicopter rotor reduces the power used during forward flight (Popular Mechanics 1996). A reduction in power allows for a smaller, lighter motor and reduces the amount of fuel needed to complete a given mission. Also, being able to achieve lift from a rotor that is not consuming power is a giant advantage. On the ground system, the use of small tracks will also be a great advantage. The tracks, which are constructed of rubber, are lightweight but still provide the durability and performance required of the Choctaw.

The obvious disadvantage to the Choctaw is the inability to hover without the addition of a tail rotor or something to counteract the torque. This is no small problem since the ability to hover is one of the requirements in the specification. Another problem is that it takeoff method is pseudo-vertical rather than truly vertical (Rotorcraft Page Feb 10, 2001). As the main rotor is powered, it begins to rotate faster and faster until the aircraft spontaneously lifts off the ground. Once airborne, the power to the rotor must be cut to prevent vehicle rotation. Also, the aircraft must begin forward flight to remain aloft. The result of all this is that the vehicle has the ability to takeoff without moving forward but cannot climb vertically. Another disadvantage is that the vehicle will not be totally silent.

2.4 Concept 2D "Oiseau"

The fourth concept is the flapping wings concept (see figure 4). In most conventional aircraft, the functions of power and lift are separated. Lift is provided by the rigidly outstretched wings and changes in geometry are limited to the movement of surfaces such as ailerons and flaps. Propellers or jet engines provide the power to move the aircraft forward through the air so that the wings can generate lift. In flapping wing flight, however, the wings provide both lift and propulsion (DeLaurier 1993,125-130).

Clearly, flapping flight depends on the up and down movements of the wings - an upstroke and a downstroke. The relative wind comes from below the wing during the downstroke, and from above the wing during the upstroke. The wing must therefore constantly twist around its long axis so it has the appropriate angle of incidence at each point in the flapping cycle (Archer and Sapuppo 1979).

Lift and propulsion are both produced during the downstroke. The wing is powered downwards and forwards, with its leading edge tilted down. The wing generates lift at right angles to the relative wind and thus there is a forward-directed thrust imparted to the vehicle during the downstroke. The inner part of the wing has less up and down motion so it behaves more like a fixed wing - the tip is able to do more work (Ellington 1984).

Lift is produced in the upstroke as well. Despite the change in the relative wind angle, the wing can still produce lift if the wing flips to a nose-up position. However, this lift is accompanied by significant drag. To diminish this, birds and bats partially fold their wings during the upstroke (Cone 1968).

The reciprocating chemical muscle (RCM) generates the power for the flapping wings. The RCM is a regenerative device that converts chemical energy into motion through a direct chemical reaction. Hence, the concept of a "muscle" as opposed to an engine. There is no combustion-taking place nor is there an ignition system required. The RCM is not only capable of producing autonomic wing flapping, but also small amounts of electricity for control of sensors and other electrical components. The RCM also creates enough gas to energize circulation-controlled airfoils (Georgia Tech 2001).

There are several benefits to a flapping wings concept. The anticipated noise level is very low. From afar, the vehicle will look like a bird. These characteristics give the Ouiseau unique stealth properties. There are also benefits to using the reciprocating chemical muscle. The system converts chemically bound potential energy directly into kinetic energy with high efficiency. Additionally, since there is no combustion, the vehicle will have a low thermal signature. The device also is capable of generating electricity on its own thus eliminating the need for parasitic generation devices.

There are several disadvantages that go along with a flapping wing concept. While there is work being done for flapping wing flight, the technology has only been demonstrated for small vehicles. This represents a significant technological risk. For example, it is not known at this point if the wings will be prohibitively large. Another problem would be the method

and development of controls systems. Yet another disadvantage is the possibility that the vehicle will experience a significant amount of vibration. This is undesirable because a stable platform may be required for sensor packages.

3.0 Selection of Final Concept

An evaluation matrix, located in Table 1, was used to compare concepts. According to the results of our evaluation, the Oiseau scored highest overall. The Oiseau meets all of the primary requirements, and scored equal or higher than the other concepts in important categories, such as ability to meet cruise speed, ability to meet VROC requirement, and ability to execute the flight profile. In addition, the Oiseau ranks highest in survivability due to its bird-like appearance and its exceptional flight agility.

The Oiseau has the most potential for development, as well as the most potential to perform the tasks required while keeping the gross weight of the vehicle to a minimum. Currently, research is being conducted in this field of aerodynamics, and many advances have been made. Within the next twenty years, technology will progress to the point where the questions that there are about this system today will be non-existent. This vehicle, while not production-ready today, can become an integral part of the armed forces of the future.

4.0 Issues for Selected Concept

4.1 Development Issues

There are many technical development issues associated with the concept. A Reciprocating Chemical Muscle must be developed to provide propulsion. Ailerons and Flaps need to be designed to provide adequate lift for the vehicle. The wings must be design to scale to provide flight and hoverability. Mechanical joints need to be developed to withstand forces created by high-frequency motion. Materials that can operate under high stresses must be developed. Dampening devices must be design for the vehicle so that it may remain steady during flight.

4.2 Programmatic Issues

The programmatic issues involve schedule, cost, risk, testing, and verification. A twenty-five-year life-cycle schedule is needed to show the major milestones of development and to emphasis the time allocated for developmental research. Cost is a major issue that involves the enabling technologies, development of technologies, risk assessment, prototype, operational test, and disposal. Testing of the system includes prototype testing, development test, and operational test. Verification of the concept includes manufacturing processes verification and production rate verification.

4.3 Phase 3 Plan

The plan for the next phase involves modifying the vehicle structure so that it can provide improved aerodynamic performance. Research of the components will be conducted in order to overcome the obstacles of the developmental issues. Cost issues will be researched. Educated predictions will be conducted in order to design a product that is economically and technologically feasible within the time period.

5.0 Illustrations

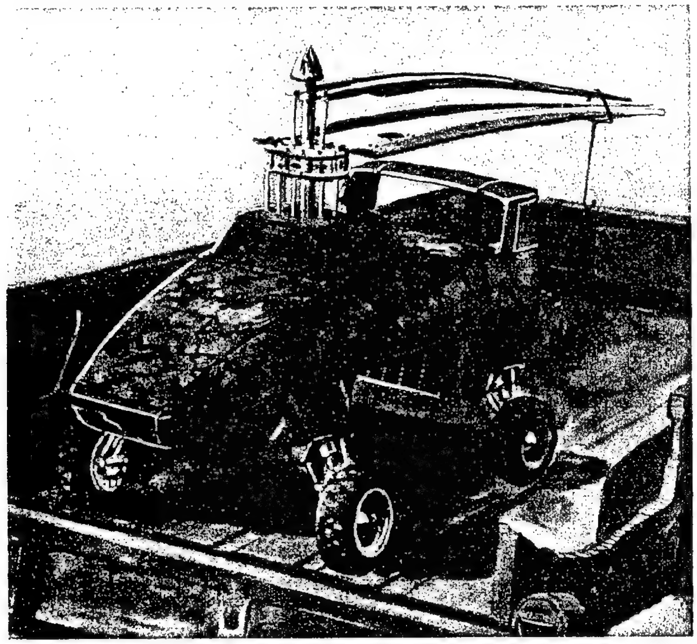

Figure 1. Concept 2A "Pawnee"

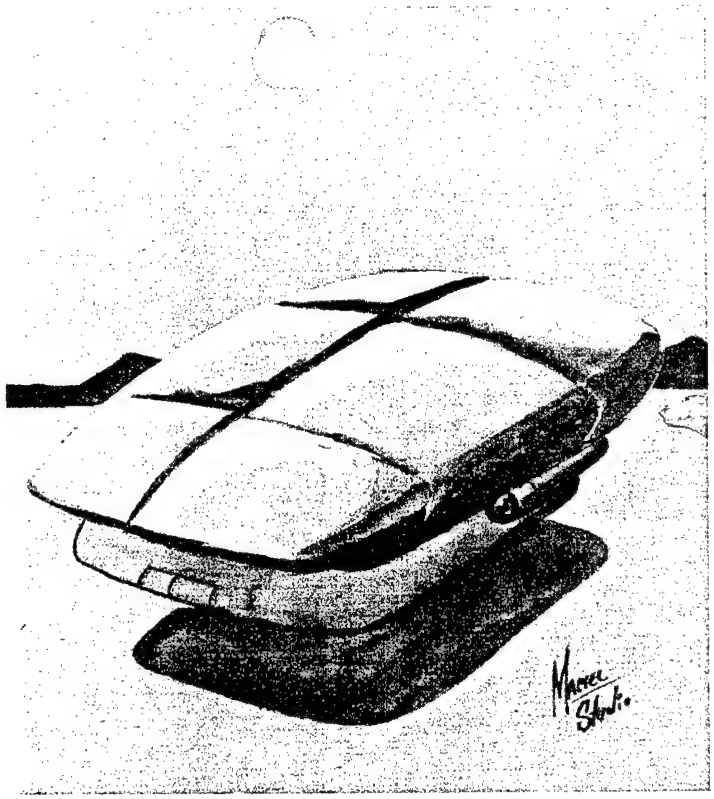

Figure 2. Concept 2B "Blowfish"

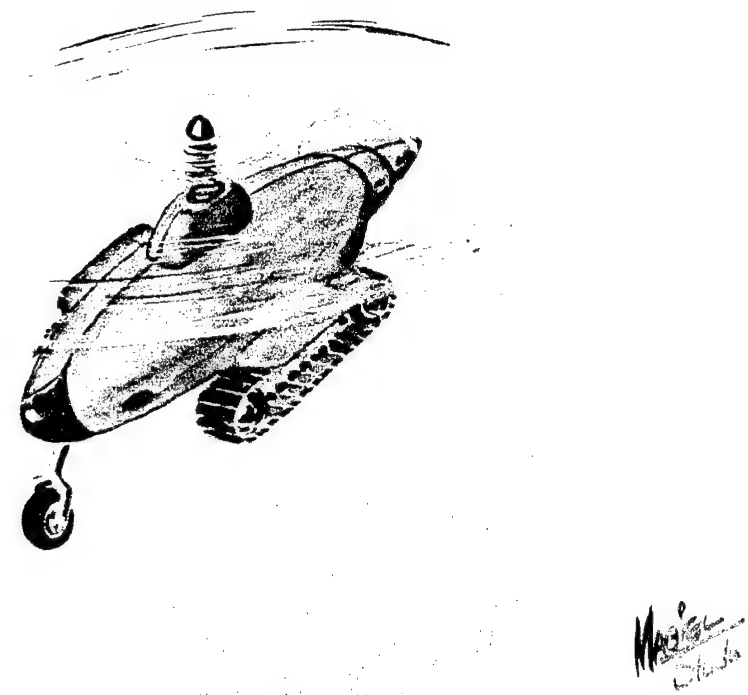

Figure 3. Concept 2C "Choctaw"

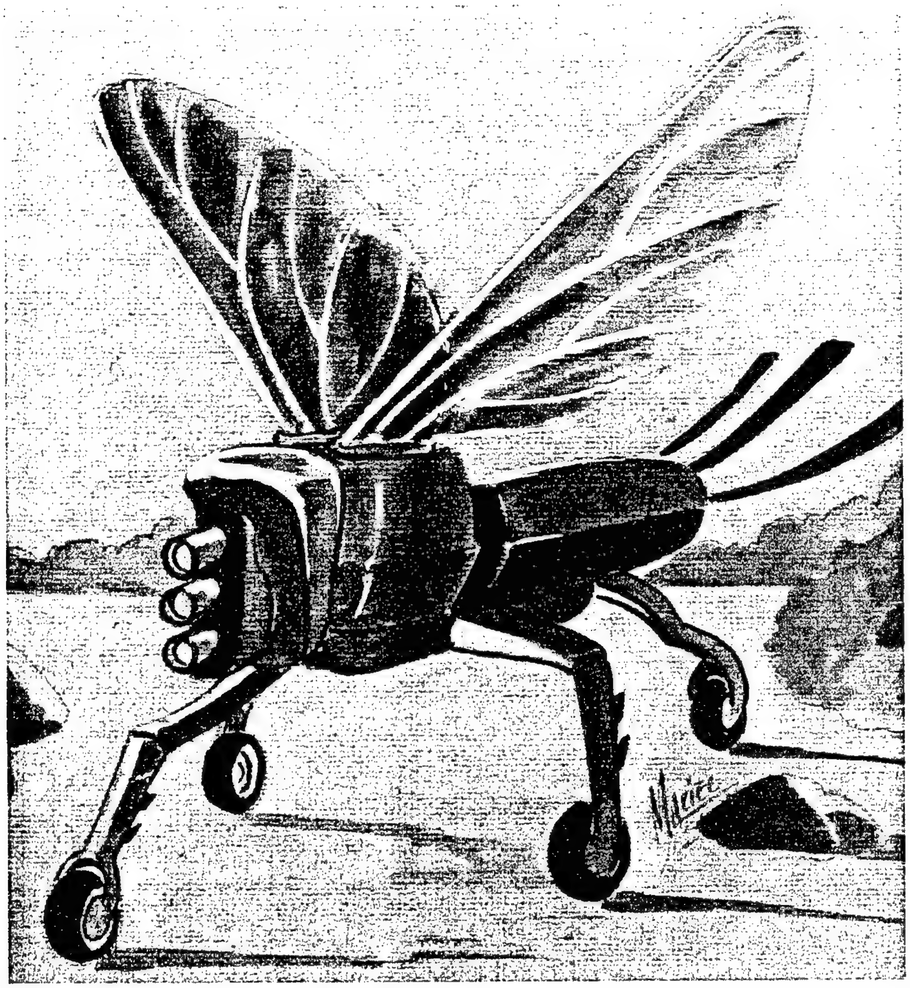

Figure 4. Concept 2D "Oiseau"

Table 1. Concept Evaluation Matrix

The purpose of the concept evaluation matrix is to determine which concept is the best to select for as the final concept. Each one of the major specifications is listed and then given a "factor" which relates to the importance of that specification to the overall mission. Each one of the four concepts is then rated on how well it can perform that specification of the mission profile. If the concept can perform that specification and above the requirement, it is given a "+" (worth 1 point), if it performs the specification substantially, it is left blank (worth 0 points), and if the concept cannot perform a given specification, it is given a "-" for that specification (worth –1 point). The points are then totaled and a normalizing factor is introduced so that the three team-concepts have scores that can be related to the score for the baseline.

	Factor	Baseline	Blimp	Autogyro	Flapping Wings
Range: 15 km from launch point	1	+	+	+	+
Cruise Speed of 30 km/hr	1	+		+	+
VROC of 250 ft/min	1			+	+
VTOL Capability	1	+	+	–	
Payload: 60 lbs	1	+	+	+	
Operational Altitude of 0 to 500 ft AGL	1	+	+	+	+
Hover to full flight profile	1	+	–	–	
Autonomous or Semi-autonomous	2	–	+	+	+
Near Quiet Acoustic Signature	2	–	+		
BLOS communications	2		+	+	+
Cost/Risk/Schedule	2	+	+		–
Potential Reliability (RAM)	2	+	+	+	
Survivability	2				+
Agility Flight	2		–		+
Visual Sensor Package	2		–	+	+
Normalizing Factor	10/6	10	15	18	20

Table 2. Concepts Comparison

Comparison Criteria	Baseline	Blimp	Autogyro	Flapping Wings
Overall Specifications				
Air Configuration	Coaxial Rotor	Ducted Fan	Auto-gyro	Flapping wings
Ground Configuration	Wheels	Hovercraft	Mattracks	Wheels
Payload Mass, kg (lb)	(60 lb)	60 lb	60 lb	60 lb
Gross Takeoff Weight. kg (lb)	(618lb)			
Energy Source for Air Transport	JP-8	Electric	JP-8	RCM
Energy Source for Ground Transport	JP-8	Electric	JP-8	Electric
Hovering Power, Kw (hp)	(60 hp)	0		
Cruise Power, Kw, (hp)			150 hp	
Total Energy for Mission Profile, KJ (BTU)				
Basis of Autonomy	none			
Primary BLOS Method				
Primary Structural Material	Magnesium Alloy	Magnesium Alloy	Carbon Fiber	Carbon Fiber
Key Technology 1	existing			RCM
Key Technology 2	existing			
Key Technology 3	existing			
Key Technology 4	existing			
User Selected 1				
User Selected 2				
User Selected 3				

References

Adaptive Aerofoils
www.nurseminerva.co.uk/adapt/flap1.htm. Accessed: February 8, 2001.

Archer, R.D., Sapuppo, J. & Betteridge, D.S. "Propulsion characteristics of flapping wings." Aeronautical Journal 83 (1979): 355–371

avdil.gtri.gatech.edu/RCM/RCM/Entomopter/AUVSI-97_EntomopterPaper.html. Accessed: February 19, 2001.

Brie, Reginald. The Autogyro and How to Fly It. Bath: Pitman Press, 1934

CarterCopters, Inc. www.cartercopters.com/..Accessed: February 11, 2001.

Cone, C.D. "The aerodynamics of flapping bird flight." Special Scientific Report of the Virginia Institute of Marine Science 52 (1968)

DeLaurier, J.D. "An aerodynamic model for flapping-wing flight." Aeronautical Journal 97 (1993): 125–130

Ellington, C., "The Aerodynamics of Flapping Animal Flight," American Zoology, vol. 24, 1984

Garvey, William. "Gyrocopters Grow Up." Popular Mechanics, June 1996

Neoteric Hovercraft, www.neoterichovercraft.com

Rotorcraft Page. www.rotorcraft.com. Accessed: February 10, 2001.

Bibliography

Adaptive Aerofoils
www.nurseminerva.co.uk/adapt/flap1.htm. Accessed: February 8, 2001.

Archer, R.D., Sapuppo, J. & Betteridge, D.S. "Propulsion characteristics of flapping wings." Aeronautical Journal 83 (1979): 355–371

avdil.gtri.gatech.edu/RCM/RCM/Entomopter/AUVSI-97_EntomopterPaper.html. Accessed: February 19, 2001.

Azuma, A., Springer - Verlag, The Biokinetics of Flying and Swimming, Tokyo, 1992, pp. 77 - 154.

Berry, John. 2001. Interview by author. Huntsville, AL.17 February.

Brie, Reginald. The Autogyro and How to Fly It. Bath: Pitman Press, 1934

Brodsky, A., The Evolution of Insect Flight, Oxford; New York: Oxford University Press, 1994, pp 35 - 39.

Brooks, Peter W. Cierva Autogiros. Washington: Smithsonian Institution Press, 1988

CarterCopters, Inc. www.cartercopters.com/..Accessed: February 11, 2001.

Cone, C.D. "The aerodynamics of flapping bird flight." Special Scientific Report of the Virginia Institute of Marine Science 52 (1968)

Corsetti, Dr. Charles. 2001. Interview by author. Huntsville, AL. February 12, 2001.

DARO.1997. www.darpa.mil/tto/MAV/mav_auvsi.html. Accessed: February 11, 2001.

Davis, W.R., "Micro UAV," Presentation to 23rd Annual AUVSI Symposium, 15-19 July 1996.

DeLaurier, J.D. "An aerodynamic model for flapping-wing flight." Aeronautical Journal 97 (1993): 125–130

Dinges, Jim. 2001. Interview by author. Huntsville, AL.13 February.

Ellington, C., "The Aerodynamics of Flapping Animal Flight," American Zoology, vol. 24, 1984

Flapping wings; touch.caltech.edu/home/publications/nick/mems00/mems00.pdf. Accessed: February 17, 2001.

Flynn, A., and Brooks, R., *Twilight Zones and Cornerstones: A Gnat Robot Double Feature*, MIT AI Laboratory Memo 1126, July 1989.

Frank M. White, Fluid Mechanics, McGraw-Hill, Hightstown NJ (1994).

Garvey, William. "Gyrocopters Grow Up." Popular Mechanics, June 1996

Georgia Institute of Technology; Article gtresearchnews.gatech.edu/reshor/rh-spr97/microfly.htm. Accessed: February 10, 2001.

The Groen Brothers Aviation Home Page. www.groenbros.com/. Accessed: February 17, 2001.

Hundley Richard O., Gritton, Eugene C., "Future Technology-Driven Revolutions in Military Operations," Documented Briefing of the RAND National Defense Research Institute, December 1992.
Lighthill, J., Mathematical Biofluiddynamics, Society for Industrial and Applied Mathematics, 1975, pp. 179 - 195.

Maciel, Alex. 2001. Interview by author. Huntsville, AL. 22 February.

McInnis, Pat. 2001. Interview by author. Huntsville, AL.12 February.

Micro air vehicles; www.ukdf.org.uk/ts6.html. Accessed: February 13, 2001.

Neoteric Hovercraft, www.neoterichovercraft.com

Neville I. Marzwell, and David Parish, December 7-9, 1993, **Miniature Robotic Vehicle with Hybrid Ground and Air Mobility,** Anaheim, California, USA.

Pennycuick, C.J., Klaasen, M., Kvist, A. & Lindström, Å. "Wingbeat frequency and the body drag anomaly: wind tunnel observations on a thrush nightingale (*Luscinia luscinia*) and a teal (*Anas crecca*)." Journal of Experimental Biology 199 (1996): 2757–2765

Phlips, P. J., East, R. A. & Pratt, N. H. "An unsteady lifting line theory of flapping wings with application to the forward flight of birds." Journal of Fluid Mechanics 112 (1981): 97–125.

Rotorcraft Page. www.rotorcraft.com. Accessed: February 10, 2001.

S. L Dixon, Fluid Mechanics and Thermodynamics of Turbomachinery, Butterworth-Heinmann, Woburn MA, (1998)

Sanders, Jim. 2001. Interview by author. Huntsville, AL. 14 February.

Truefly; www.chez.com/truefly/Images/trueflya.htm Accessed: February 13, 2001.

Universal Hovercraft, www.hovercraft.com

Universal Hovercraft, Hovercraft - Constructions and Operation, Universal Hovercraft, Cordova IL, (1994)

Walker, G.T. "The flapping flight of birds. I." Journal of The Royal Aeronautical Society 29 (1925): 590–594.

Walker, G.T. "The flapping flight of birds. II." Journal of The Royal Aeronautical Society 31 (1927): 337–342.

Ward-Smith, A., Biophysical Aerodynamics and the Natural Environment, John Wiley & Sons, New York, 1984, pg. 93.

Welham, C.V.J. "Flight speeds of migrating birds: a test of maximum range speed predictions from three aerodynamic equations." Behavioural Ecology 5 (1994): 1–8.

Young, Suzi. 2001. Interview by author. Huntsville, AL. 13 February.

Word List

Word	Comments
AGL	Above Ground Level
AIAA	American Institute of Aeronautics and Astronautics
AMCOM	United States Army Aviation and Missile Command

BLOS	Beyond Line of Sight
BTU	British Thermal Unit
C Band	Communication Band
CAD	Computer aided design
CM	Communication
Concept Description Document (CDD)	Document that details the customer's technical specifications for the UA/UGV
CST	Central Standard Time
Customer	John Fulda and Jim Winkeler
Dry Weight	Weight not including fuel
EE	Electrical Engineering
EH	English
EM	Engineering Management
EST	Editorial Support Team
ESTACA	Ecole Superieure des Techniques Aeronautiques et de Construction
FLOT	Forward Line of Troops
Fpm	Feet per minute
Ft	feet
GPS	Global Positioning System
IPT	Integrated Product Team
IRP	Intermediate Power Rating
JAUGS	TBD
JCDL	TBD
Joint Vision 2020	TBD
Kg	Kilogram
Km	Kilometer
kW	Kilowatt
lbs.	Pounds
LIDAR	LIght Detection And Ranging
MAE	Mechanical and Aerospace Engineering
MKT	Marketing
MSFC	Marshall Space Flight Center
MULE	Modular Unmanned Logistics Express
MULE	Modular Unmanned Logistics Express
NASA	National Aeronautics and Space Administration
nm	Nautical miles (~2025 yds)
Payload	Item carried by the system having a specified weight
Phase 1	Baseline review, conducted on conventional configuration using current and experimental technology, assess technologies clarify the Concept Description Document
Phase 2	Alternative concepts review, development and evaluation of four prototype designs to meet customer

	specifications. Select a preferred design.
Phase 3	Final Evaluation, detailed design specifications of selected design concept
RCM	Reciprocating Chemical Muscle
RFP	Request for Proposal
RMA	Revolution of Military Affairs
Style Guide	Document that specifies the mechanics of writing documents required for the project
TBD	To be determined (not know at this time)
TBE	Teledyne Brown Engineering
TF/TA	Terrain following/terrain avoidance
UAGV	Unmanned Air-Ground Vehicle
UAH	The University of Alabama in Huntsville
UAV	Unmanned Air Vehicle
UGV	Unmanned Ground Vehicle
U.S.	United States
VROC	Vertical rate of climb
VTOL	Vertical takeoff and landing

Appendix C - France Travel Team

NAME AS IT APPEARS ON PASSPORT	NATIONALITY	PASSPORT EXPIRATION DATE
Melanie Giovanna Janetka	US	
James Benjamin Bramblett	US	
Damon Nixon Hay	US	
Christopher Hirstein	US	
Demetrius Peoples	US	

After the purchase of plane tickets, excess funds will be divided equally per capita and used for food and entertainment on the trip.

Appendix D - Team Member Resumes

Ségolène Brantshcen

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FRANCE
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Permanent Address
BP48
98842 Nouméa Cedex
Nouvelle Calédonie

Key Words

Mechanical Engineering, Aerospace Engineering, Thermo-fluid Engineering, CATIA, Fluent, Nastran, French, Chinese

Education

ESTACA Levallois-Perret, France

Five year program in Mechanical/Aerospace Engineering

Expected graduation date: Jun 2002

- Minor: Chinese
- GPA: 3.8/4.0
- Work Sample: http://mortonweb.uah.edu/ipt2001/BrantshcenS_work.pdf
- Relevant Coursework: thermodynamics, fluid mechanics, turbulence, dynamics, design, aerodynamics, aerospace structures, propulsion, orbital mechanics, numerical methods, measurement process

Technical Skills

- Operating Systems: Windows 95, 98, NT, and DOS
- Computer Languages: JAVA, C++
- CAD / FEM Systems: AutoCAD 13, CATIA, Fluent, Nastran
- Major Software Packages: MS Office 98 (including Access)

Work Experience

Jun 1999 – Aug 1999 Eurocopter, EADS subsidiary
Paris area, France

Assistant Production Manager

- Analyzed the department's organization.
- Analyzed raw materials stock in the production department and recommended solutions to reduce stock.

Sep 1998 – Jun 1999 ESTACA BDE Levallois-Perret, France

Team Member

- Published the school magazine.
- Assisted the President of the BDE (student activity association) as a secretary.

Jun 1998 – Aug 1998 Microdyne Systems, Inc. Greensboro, NC

Trainee

- Analyzed and streamlined the company's organization.
- Created and modified technical drawings on AutoCAD 13.

James B. Bramblett

School Address
4611 Governor's House Dr., Apt. 507
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Permanent Address
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Phone (256) 882-6955

E-mail bramblj@email.uah.edu

Key Words
Mechanical Engineering, Co-op Experience, Fluid Flow Analysis

Education

University of Alabama in Huntsville — **Huntsville, AL**

Bachelor of Science, Mechanical Engineering
Expected graduation date: May 2001

- **Relevant Coursework: thermodynamics, mechanics of materials, fluid mechanics, dynamics, design project, machine design, aerospace propulsion, probability and statistics, heat & mass transfer**
- **Work Sample: http://mortonweb.uah.edu/ipt2001/BramblettJ_work.pdf**
- **Honors: Academic Excellence Scholarship Recipient**

Technical Skills

- **Operating Systems: Windows 95, 98, NT, and DOS**
- **Computer Language: FORTRAN**
- **Applications: Design Flow Solutions**
- **Major Software Packages: MS Office**

Work Experience

Jun 2000 – Present — **Thermal Corporation** — **Madison, AL**

Co-op Engineer

- **Participate in research and development projects directed at improving products and manufacturing processes.**
- **Conduct cost and labor time studies.**

Sep 2000 – Dec 2000 — **University of Alabama in Huntsville** — **Huntsville, AL**

Independent Contractor for Boeing

- **Used special software to model and analyze an airflow system.**
- **Created two models for performance comparison.**

Engineering Intern

- Designed and supervised the construction of a vacuum system for the removal of pyrites from coal pulverizers.
- Involved with outage maintenance planning for the replacement of valves as well as pulverizer support equipment.

References Available on Request

Damon N. Hay

1507 S. Madison St.
Athens, AL 35611
Phone (256) 232-1211

Email dhay@ebs330.eb.uah.edu

Key Words

Mechanical Engineering, Machining, Machine Fitting/Assembly, Computer Hardware, Industrial Maintenance, Quality Control

Education

The University of Alabama in Huntsville
Huntsville, AL

Bachelor of Science, Mechanical/Aerospace Engineering

Expected graduation date: May 2001

- Relevant Coursework: thermodynamics, materials science, fluid mechanics, dynamics, basic circuits, design, aerodynamics, experimental techniques in solid mechanics
- Work Sample:http://mortonweb.uah.edu/ipt2001/HayD_work.pdf

Technical Skills

- Operating Systems: Windows 95, 98, NT, and DOS
- Computer Languages: FORTRAN, Visual Basic
- CAD / FEM Systems: AutoCAD 12
- Major Software Packages: MS Office 2000 (including Access)

Work Experience

Jan 1993 – Present Humco Corporation Athens, AL

Land Management

- Oversee three farms and other miscellaneous acreage (200 acres total) located in Limestone County, Alabama.
- Act as Liaison between owner and USDA, tenants, and attorneys.

Jan 1993 – Present Humco Corporation Athens, AL

House Building

- Assisted in the developing and building of over 60 houses located in phases 2, 3, & 4 of Hay's Mill Subdivision located in Carrollton, GA.

front end loaders, bush hogging, etc.).

- Carry out maintenance on assorted trucks and tractor.

Sep 1979– Jan 1993 General Machine and Fabrication Decatur, AL

Machinist/Toolmaker

- Read blueprints and construct close tolerance parts (± 0.0005 T.I.R.) and machine tools per specifications utilizing lathes, vertical & horizontal mills, saws and various other machining tools/operations.
- Quality control/Inspection of parts to required specifications.
- Six years of industrial maintenance

References Available on Request

Christopher Hirstein

3784 University Dr., Apt. 1722
Huntsville, AL 35816
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Email hirstec@email.uah.edu

Key Words

Mechanical Engineering, Aerospace Engineering, AutoCAD, FORTRAN, Turbojet Engines, Buckling

Education

The University of Alabama in Huntsville
Huntsville, AL

Bachelor of Science, Mechanical/Aerospace Engineering

Expected graduation date: May 2001

- GPA: 3.0/4.0 (in major)
- Relevant Coursework: thermodynamics, materials science, fluid mechanics, dynamics, basic circuits, design, aerodynamics, aerospace structures, aircraft stability and control, propulsion, high tech venturing
- Work Sample: http://mortonweb.uah.edu/ipt2001/HirsteinC_work.pdf
- Honors and Affiliations: Freshman Merit Scholarship, Scholars List (Fall 1999), Honor Scholar List (Spring 2000), Student Member of AIAA
- Projects: Column Buckling of Composite Carbon Fiber Beams, Thrust and Cycle Analysis of Turbojet Engine

Technical Skills

- Operating Systems: Windows 95, 98, NT, and DOS
- Computer Language: FORTRAN
- CAD / FEM Systems: AutoCAD 12 & 14
- Major Software Packages: MS Office 2000

Work Experience

May 1999 – Present US Space and Rocket Center
Huntsville, AL

Banquet Server

down dinners.

- Assist in the fast food court when needed.
- Awarded Temporary Employee of the Month in September 2000

May 1996 – Aug 1997 Chavond Barry Engineering
Blawenburg, NJ **Assistant Records Advisor**

- Organized and entered company records into computer database.
- Performed basic clerical duties.

References Available on Request

Melanie G. Janetka

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Phone (630) 852-6661

Key Words

Mechanical Engineering, Aerospace Engineering, AutoCAD, FORTRAN, Composite Materials, Propulsion

Education

The University of Alabama in Huntsville
Huntsville, AL

Bachelor of Science, Mechanical/Aerospace Engineering

Expected graduation date: May 2001

- GPA: 3.2/4.0
- Relevant Coursework: thermodynamics, materials science, fluid mechanics, dynamics, basic circuits, design, aerodynamics, aerospace structures, aircraft stability and control, propulsion, composite materials, experimental stress analysis, instrumentation
- Work Sample: http://mortonweb.uah.edu/ipt2001/JanetkaM_work.pdf
- Honors and Affiliations: Pi Tau Sigma Mechanical Engineering Honor Society (Vice President), American Society of Civil Engineers (Treasurer), American Helicopter Society (UAH Chapter founding member), American Institute of Aeronautics and Astronautics

Technical Skills

- Operating Systems: Windows 95, 98, Macintosh
- Computer Languages: FORTRAN, C
- CAD / FEM Systems: AutoCAD 11 & 14
- Major Software Packages: MS Office 2000, Corel Office

Work Experience

May 1999 – Present Propulsion Research Center
Huntsville, AL

Research Assistant Optician

- Designed and built water tunnel facility.
- Supervised undergraduate in facility construction.
- Personally welded steel structure, constructed wood structure, fiber glassed large tank, and installed plumbing.

May 1998 – May 1999 Payless Optical Outlet
Huntsville, AL

Optician

- Made eyeglasses (cut, tinted, and coated lenses).
- Measured customers for bifocal, trifocal, and progressive lenses.
- Dispensed, adjusted, and repaired eyeglasses.
- Completed daily balance sheets and made bank deposits.
- Opened and closed store and lab

Jon Kilpatrick

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Key Words

Mechanical Engineering, Visual Basic, FORTRAN, Solid Edge, I-DEAS, BRL-CAD, Matlab, 3DStudioMax, 3DLinX

Education

The University of Alabama in Huntsville
Huntsville, AL

Bachelor of Science, Mechanical/Aerospace Engineering

Expected graduation date: May 2001

1. GPA: 3.2/4.0
2. Relevant Coursework: thermodynamics, heat and mass transfer, machine component design, design, fundamentals of aerodynamics, CAD-CAM, fluid mechanics, design of thermal systems
3. Work Sample: http://mortonweb.uah.edu/ipt2001/KilpatrickJ_work.pdf
4. Honors and Affiliations: Pi Tau Sigma Mechanical Engineering Honor Society

Technical Skills

5. Operating Systems: Windows 95, 98, NT, 2000
6. Computer Languages: FORTRAN, Visual Basic
7. CAD Systems: Solid Edge, I-DEAS, BRL-CAD
8. 3D Visualization Systems: 3DStudioMax, 3DLinX

Work Experience

Jul 1998 - Present ITT Industries
Huntsville, AL

Student Engineer/Researcher

9. FY'00 – Enhanced Fiber Optic Guided Missile (EFOGM). Developed an integrated missile simulator for EFOGM using Visual Basic and 3DLinX.
10. FY'99 – Smart Weapons Management Office (SWMO). Digitally converted and analyzed orthogonal x-ray sets of shaped charge warheads to assess flight path particle trajectories and velocities in a 3D Cartesian coordinate system.
11. FY'99 – National Missile Defense (NMD) witness plate analysis. Responsible for the post-test analysis and documentation of three NMD hit-to-kill tests against flat plate targets. Measured hole sizes in plates, analyzed debris impact damage to witness plates, and formulated model for debris spread as function of strike angle.
12. FY'98 and '99 – Theater High Altitude Area Defense (THAAD) Light Gas Gun test support. Tested support for hit-to-kill of simulated Chemical/Biological targets at the UAH Aero-Physics Facility. Developed method for determining fluid velocities from chemical targets. Supported test setup efforts, post-test debris sorting, debris analysis, and development of final reports.
13. FY'98 – Patriot Advanced Capability-3 (PAC3) gun test support. Gun test support for the PAC-3 Live Fire Test and Evaluation (LFT&E) hit-to-kill tests. Supported test

Shane Lackey

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Arab, AL 35016
Phone (256) 586-3011

Key Words

Mechanical Engineering, Aerospace Engineering, Secret Clearance Pending, Thermal Analysis, I-DEAS, Solid Edge, C++

Education

The University of Alabama in Huntsville
Huntsville, AL

Bachelor of Science, Mechanical/Aerospace Engineering

Expected graduation date: May 2001

- Relevant Coursework: thermodynamics, materials science, fluid mechanics, dynamics, basic circuits, design, aerodynamics, aerospace structures, aerospace propulsion
- Work Sample: http://mortonweb.uah.edu/ipt2001/lackeys_work.pdf

Technical Skills

- Operating Systems: Windows 95, 98, 2000, NT
- Computer Language: C++
- CAD Systems: I-DEAS, Solid Edge
- Major Software Packages: MS Office 2000, MathCAD

Work Experience

Aug 2000 – Present SY Technology
Huntsville, AL

Junior Engineer

- Plan for wind tunnel tests and studied different aspects of missile design.
- Design optics system for prototype testing.

Jan 2000 – May 2000 Alabama Department of Transportation
Clayville, AL

Geometry Teacher

- Taught geometry to department workers for college credit.

References

Available on Request

Demetrius Peoples

20381 Winfred Dr.

P.O. Box 62

Tanner, AL 35671
Phone (256) 232-1974
Email peoplesd@email.uah.edu

Key Words — **Mechanical Engineering, AutoCAD, CAD/CAM, Thermal Analysis, FORTRAN**

Education — The University of Alabama in Huntsville — Huntsville, AL

Bachelor of Science, Mechanical Engineering

Expected graduation date: May 2001

- Relevant Coursework: thermodynamics, materials science, fluid mechanics, dynamics, basic circuits, heat and mass transfer, analysis of engineering systems, machine design, thermal design, kinematics of machines
- Work Sample: http://mortonweb.uah.edu/ipt2001/PeoplesD_work.pdf
- Honors and Affiliations: National Society of Black Engineers, American Society of Mechanical Engineers

Technical Skills

- Operating Systems: Windows 95, 98, NT
- Computer Languages: FORTRAN
- CAD/FEM Systems: AutoCAD 12 and 14, CAD/CAM
- Major Software Packages: MS Office

Work Experience — **Oct 1999 - Present** — **McRae's** — **Huntsville, AL**

Sales Associate

- Build client relations to increase sales profits.

Special Projects — Jan 2001 — AMCOM — Huntsville,AL

Programmer

- Integrated unmanned air/ground vehicle.
- Performed life cycle cost and technical feasibility studies of unmanned vehicles.

Designer

- Designed a machine vise used for machining small parts.

References Available on Request

Cédric Trophardy

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Permanent Address
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Toutainville, France 27500
Phone (33) 2 32 42 49 57

Key Words

Mechanical Engineering, Aerospace Engineering, Thermal Analysis, Servo Control, Matlab/Simulink, C, MS Access, CATIA, French, German

Education

ESTACA
Levallois-Perret, France

Bachelor of Science, Mechanical/Aerospace Engineering

Expected graduation date: Jun 2002

- Minor: German
- GPA: 14.94/20 (3.5/4.0)
- Relevant Coursework: servo control, thermodynamics, materials science, fluid mechanics, dynamics, basic circuits, design, aerodynamics, aerospace structures, aircraft stability and control, propulsion
- Work Sample: http://mortonweb.uah.edu/ipt2001/TrophardyC_work.pdf
- Honors and Affiliations: Students Union, Treasurer of Talon-Pointe (student association)

Technical Skills

- Operating Systems: Windows 95, 98, 2000, NT, and DOS
- Computer Languages: Matlab/Simulink, C
- CAD / FEM Systems: Matlab/Simulink, D-Space, CATIA, ADAMS, Nastran
- Major Software Packages: MS Office 2000 (including Access)

Work Experience

Jun - Aug 1999 — US Space & Rocket Center
Huntsville, AL

Guide

- Welcomed and guided the public in the Space Museum.

June 1998 — Dassault Aviation
Argenteuil, France

Craftsman

- Prepared spare parts for an airplane assembly line.

References

Available on Request

Cédric van Essen

Key Words

Mechanical Engineering, Automotive Engineering, Servo Control, Matlab, Simulink, CATIA, Nastran, French, English, Spanish

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32 rue Castérès
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Permanent Address
3 rue des Astiers
La Ferriere, France 85280
Phone (33) 2 51 98 48 76

Education

ESTACA
Paris, France

Five-year program in Mechanical/Automotive Engineering

Expected graduation date: Jun 2002

- Minor: Spanish
- GPA: 15.87/20 (4.0/4.0 in major)
- Relevant Coursework: servo control, automotive structures, car stability and propulsion, acoustic, thermodynamics, materials science, fluid mechanics, dynamics, basic circuits, design, aerodynamics
- Work Sample: http://mortonweb.uah.edu/ipt2001/vanEssenC_work.pdf
- Honors and Affiliations: Students' Union, R.A.C.E. President

Technical Skills

- Operating Systems: Windows 95, 98, NT
- Computer Languages: C++
- CAD / FEM Systems: Matlab / Simulink, CATIA, Nastran, ADAMS
- Major Software Packages: MS Office 2000

Work Experience

Jun – Aug 1999 **Schlumberger Industries** **Normandy, France**

- Worked in the IC Module Manufacturing department.
- Programmed and controlled the machinery that fixes the IC module.

Jun – Aug 1997 & 1998 Normetex Industry
Normandy, France

- Worked in the Vacuum Pump Producing and Testing department.
- Assisted in assembling and testing $150m^3/h$ pump for a nuclear power station.

Engineering Project

- Implemented software to design a pump system.
- Designed a break system for an urban car.

References Available on Request

Nicolas Vergeneault

Key Words

Mechanical Engineering, Aeronautical Engineering, Structure and Material, CATIA, Matlab / Simulink, ADAMS, Patran, Nastran, Databases, C++, French, German

Education

ESTACA
Paris, France

Five-year program in Mechanical/Automotive Engineering

Expected graduation date: Jun 2002

- Minor: German
- GPA: 14.2/20 (3.5 in major)
- Relevant Coursework: materials science, materials resistance, structure damaging, aerospace structures, aircraft stability and control, propulsion, fluid mechanics, dynamics, basic circuits, design, aerodynamics, servo control, thermodynamics
- Work Sample: http://mortonweb.uah.edu/ipt2001/VergeneaultN_work.pdf
- Honors and Affiliations: student body president, public relations officer for the E.S.T.A.C.A. official reception

Technical Skills

- Operating Systems: Windows 95, 98, NT
- Computer Language: C++
- CAD / FEM Systems: CATIA, ADAMS, Patran, Nastran, Matlab / Simulink
- Major Software Packages: MS Office 2000

Work Experience

Jun – Aug 1999 Air France Industries Orly, France

Maintenance Assistant

- Helped maintain Boeing 747's and Airbuses A310's.
- Helped maintain aircraft landing gear.

Jun – Aug 1997 & 1998 C.A.V.A.C. Vendée, France

- Managed sorting of cereals in the Seed Production Department.

Engineering Project

- Participated in a model analysis of shock effects on structures.
- Conducted a structural analysis of the Messerschmitt 109 replica (3:4).

References

Available on Request

Timothy Alan Weaver

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608-L John Wright Dr.
Huntsville, AL 35805
Phone (256) 284-3908
Email weaver_sas@yahoo.com

Permanent Address
10010 West Red Fox Rd.
Mt. Vernon, AL 36560
Phone (334) 829-9272

Key Word C Programming, Thermocouples, Research, Mechanical Engineering, Aerospace Engineering

Education The University of Alabama in Huntsville Huntsville, AL

Bachelor of Science, Mechanical/Aerospace Engineering
Expected graduation date: Jan 2002

- GPA: 3.2/4.0
- Relevant Coursework: thermodynamics, materials science, fluid mechanics, dynamics, electrical circuits, aerodynamics, aerospace structures, propulsion, numerical methods and computations
- Work Sample: http://mortonweb.uah.edu/ipt2001/WeaverT_work.pdf
- Honors and Affiliations: National Honors Society, Pi Tau Sigma Mechanical Engineering Honors Society, Engineering Scholar's List

Technical Skills

- Computer Language: C programming
- Major Software Packages: MS Word, MS Excel

Work **Feb 2000 – Present The University of Alabama in Huntsville**
Huntsville, AL

Experience **Courier**

- Find and make copies of articles at the Redstone Arsenal Library.
- Deliver books to various libraries in the Huntsville area.

Feb 1999 - Mar 1999 The University of Alabama in Huntsville Huntsville, AL

Research Assistant

- Perform citation searches.
- Check out books for scientists in the Redstone Arsenal Library.

Jun 1998 – Aug 1998 Geocenters Huntsville, AL

Engineer's Assistant

- Assisted the engineers on board the ex-USS Shadwell with various tasks.
- Installed thermocouples and optical smoke sensors for the fire drill on board the ex-USS Shadwell.

References Available on Request

Khalid M. Zarouni

4515 Bonnell Dr. Apt. 28G
Huntsville, AL 35816
Phone (256) 890-4299
Email: kfuae@juno.com

Key Words

Computer and Electrical Engineering, Computer Networks, Software Development, Algorithms, Assembly, C, Microcomputers.

Education

The University of Alabama in Huntsville — Huntsville, AL

Bachelor of Science, Computer Engineering

Expected graduation date: Dec 2001

- GPA: 3.50/4.0 (3.8/4.0 in major)
- Relevant Coursework: C programming, electronics, Unix operating systems, data structures in C++, advanced digital logic design, microcomputers and Motorola 6800, Senior Design, VHDL, computer architecture, computer networks
- Work Sample: http://mortonweb.uah.edu/ipt2001/ZarouniK_work.pdf
- Honors and Affiliations: Muslim Students Association, Member of the Scientific Club (AbuDhabi, UAE), UAH Engineering Dean's List (2000)

Technical Skills

- Operating Systems: Windows 95, 98, 00, NT, Unix, Linux, and DOS
- Computer Languages: Assembly, Quick Basic, LabView, Turbo Pascal, C, C++, VHDL, HTML
- Platforms: PCs, Macintosh, Unix, Linux
- Applications: Visual Studios C++, Matlab, Electronics Workbench, Maxplus II, LabView, and Computer Aided Design (CAD) tools.
- Microcontrollers: Motorola 68K, Xlinax, Altera-Max, PIC

Work Experience

May 1995 – Sep 1996 GECO Electrical Engineering Company Sharjah UAE

Co-op Quality Engineer

- Performed capability studies of electrical equipment.
- Worked in business and trade section.

Projects

- Wrote VHDL programs to implement hybrid sequential and combinational designs, digital logic simulation, rapid prototyping techniques, and design for testability concepts such as scanning keypad interface, PS 2, PC keyboard interface, and computer display interface.
- Design and implement a calculator using Motorola 68000 microcontroller.
- Design and create a computer display interface using the Altera FPGAs.
- Worked on asynchronous serial case inverter using XS 40 board with the 8031 microcontroller.
- Worked on temperature sensor (TS) using the XS 40 rapid prototyping platform.

Communication Skills

- Able to communicate well in the following languages: English, Arabic, Hindi.

Appendix E – Sample Calculations

Mechanical Configuration:

Frame Weight Estimator

Material	Magnesium AZ31B	
Density	110.4192	lb/ft^3

Square Tubing Dimensions

Outer Side Length	1	in
Inner Side Length	0.875	in
Cross Section	0.234375	in^2
	0.001627604	ft^2

Weight per foot of material	0.17971875	lb/ft

Number of Pieces	Length (ft)	Total Length (ft)	Weight	
4	5.000	20.00	3.594	
8	1.167	9.33	1.677	
2	3.000	6.00	1.078	
2	2.000	4.00	0.719	
4	4.170	16.68	2.998	
8	0.833	6.67	1.198	
2	1.650	3.30	0.593	
1	1.167	1.17	0.210	
		Total Weight	12.07	lb

<u>Aeroshell Weight Estimator</u>

Material	CFS003/LTM25 Carbon/Epoxy	
Density	0.0525	lb/in^3
Ply Thickness	0.0075	in
Number of Plys	3	

Component	Area Formula	Radius (in)	Height (in)	Surface Area	
Nose	2*Pi*radius^2	10	n/a	628.32	
Forward Body	2*Pi*radius*Length	10	24	1507.96	
Aft Body	2*Pi*radius*Length	7.2	36	1628.60	
Tail	2*Pi*radius^2	7.2	n/a	325.72	
			Total	4090.6	in^2
			x Thickness of material	0.0225	in
			Total Volume	92.0	in^3
			Total Weight	4.83	lb

Total Weight of Frame and Shell 16.90 lb

Ground Robotics: Ground Speed

Max. Speed: s = 10 km/h (3.94 mph)
Pegasus weight: m = 350 kg
Max acceleration: a = 1 m/s²
Max slope: α = 30°
Motor wheel diameter: r =15cm (5.9 inch)
Gravity: g = 9.81 N/kg

Speed rotation

$$P = 2\pi\left(\frac{r}{2}\right) = 47.124cm = 18.55in$$

$$\frac{(s \cdot 1000 \cdot 100)}{60 \cdot P} = 353.68rpm$$

Motor wheel perimeter: P=2.π. (r/2)= 47.124cm (18.55 inch)
Motor wheel speed rotation: (s.1000.100)/(60.P) = 353.68 rpm

SOME COMPANIES INVOLVED IN RESEARCH on:
http://www.ballard.com/Ballard Power: Canada...predominantly working on PEFC for transportation and electric powerplants. Most of the PEFC technology was developed in house and they own over 200 patents.
Plug Power: US...is a joint venture between DTE Energy Co., the parent of Detroit Edison and Michigan's largest electric utility, and Mechanical Technology Inc. or MTI, an early

developer of fuel cell technologies. Their goal is to develop and manufacture affordable fuel cell systems for residential, small commercial and automotive applications.

Aerodynamics Calculations

frequency	2 Hz	12.56637 rad/s	
phi max	30 degree	0.523599 radians	
b (one)	7.21 ft	2.197635 m	
x max	0.549409 m		
v max	13.80815 this is velocity at midspan		
alpha	5.6 degrees	0.097738 radians	
Cd up	1.4 this is the Cd when the wing is moving downward (and the air is flow		
Cd down	0.4 this is the Cd when the wing is moving upward (and the air is flowing downwars)		
rho	1.08 kg/m3		
c tip	2.952 ft	0.899781 m	
c root	1 ft	0.304804 m	
S	4.342526 m2		
Weight	400 lbm	1779.915 N	

Cd frontal	1.5	Cd for front cross-section
Frontal Dimensions:		
	14 in	0.355604 m
	14 in	0.355604 m
Frontal Area:		0.126454 m2
top area	4.831	
top Cd	2	

time	radian	x (m)	v (m/s)	stroke	coeff (min	Lift Inst.	Thrust Ins	Forward Velocity	Integral of	Integral of Thrust
0	0	0	13.80815	up	447.1024	-177.9874	17.45182	13.84603 m/s	-3.449669	0.338243
0.02	0.251327	0.136632	13.37434	up	419.4506	-166.9795	16.37248	49.84572 km/hr	-3.036584	0.29774
0.04	0.502655	0.26468	12.10017	up	343.3359	-136.6789	13.40148		-2.312606	0.226753
0.06	0.753982	0.376096	10.06571	up	237.5881	-94.58166	9.273813		-1.456837	0.142844
0.08	1.00531	0.463881	7.398775	up	128.3677	-51.10203	5.010598		-0.680983	0.066771
0.1	1.256637	0.522519	4.266952	up	42.69448	-16.99629	1.6665		-0.17698	0.017353
0.12	1.507964	0.548325	0.867021	up	1.762768	-0.701742	0.068806		0.211713	0.022135
0.14	1.759292	0.539677	-2.587389	down	15.69855	21.87308	2.144674		1.348075	0.13218
0.16	2.010619	0.49712	-5.879223	down	81.05429	112.9344	11.07332		3.660473	0.358912
0.18	2.261947	0.423327	-8.801644	down	181.6619	253.1128	24.81793		6.608428	0.647962
0.2	2.513274	0.322934	-11.17102	down	292.6323	407.7299	39.97827		9.462656	0.927822
0.22	2.764602	0.202251	-12.83849	down	386.513	538.5356	52.80388		11.51706	1.129258
0.24	3.015929	0.068859	-13.69926	down	440.0791	613.1703	60.12187		12.26341	1.202437
0.26	3.267256	-0.068859	-13.69926	down	440.0791	613.1703	60.12187		11.51706	1.129258
0.28	3.518584	-0.202251	-12.83849	down	386.513	538.5356	52.80388		9.462656	0.927822
0.3	3.769911	-0.322934	-11.17102	down	292.6323	407.7299	39.97827		6.608428	0.647962
0.32	4.021239	-0.423327	-8.801644	down	181.6619	253.1128	24.81793		3.660473	0.358912
0.34	4.272566	-0.49712	-5.879223	down	81.05429	112.9344	11.07332		1.348075	0.13218
0.36	4.523893	-0.539677	-2.587389	down	15.69855	21.87308	2.144674		0.211713	0.022135
0.38	4.775221	-0.548325	0.867021	up	1.762768	-0.701742	0.068806		-0.17698	0.017353

time	radian	x (m)	v (m/s)	stroke	coeff (min	Lift Inst.	Thrust Ins	Forward Velocity	Integral of	Integral of Thrust
0.38	4.775221	-0.548325	0.867021	up	1.762768	-0.701742	0.068806		-0.17698	0.017353
0.4	5.026548	-0.522519	4.266952	up	42.69448	-16.99629	1.6665		-0.680983	0.066771
0.42	5.277876	-0.463881	7.398775	up	128.3677	-51.10203	5.010598		-1.456837	0.142844
0.44	5.529203	-0.376096	10.06571	up	237.5881	-94.58166	9.273813		-2.312606	0.226753
0.46	5.78053	-0.26468	12.10017	up	343.3359	-136.6789	13.40148		-3.036584	0.29774
0.48	6.031858	-0.136632	13.37434	up	419.4506	-166.9795	16.37248		-3.449669	0.338243
0.5	6.283185	1.33E-15	13.80815	up	447.1024	-177.9874	17.45182	Sum of	Lift of one \	Thrust of one wing
									55.65289	9.818381
									Lift of all wi	T of all wings (2)
									111.3058	**19.63676**

Aero. Lift ('	Aero Lift (2	Total Lift
1708.357	3416.714	**3528.02**

Explanation of Variables:

Frequency is the rate of the wing flapping

Phi Max is the maximum angle that the wing makes with horizontal and maximum position

B is the wing span

X max is the maximum vertical position of the midspan of the wing

V max is the maximum velocity of the wing

Alpha is the angle of attack

C_d up is the drag coefficient when the wing is moving downward

C_d down is the drag coefficient when the wing is moving upward
Rho is the density of the air at 4000 ft altitude
C tip is the chord length at the tip of the wing
C root is the chord length at the root of the wing
S is the planform area of the wing
C_d frontal is the drag coefficient of the body flying forward
Frontal dimensions and frontal area are with respect to the part of the body that is facing into the wind during flight

Within the spreadsheet:
X is the vertical location of the wing at time t
V is the velocity of the wing at time t
Lift is the instantaneous lift of the wing at time t
Thrust is the instantaneous thrust at time t
Forward velocity is the average velocity of the vehicle during one cycle
Integral of thrust and lift was calculated using the trapezoidal rule from the instantaneous velocity within one time step
The total thrust and lift with one wing is the sum of the integral of the thrust for one wing
The total thrust and lift is dependent on how many wings are flapping at a given time

$t_i=(2\pi/f+25)+t_{i-1}$
$x_i=xmax*\sin\theta$
$v_i=vmax*\cos(\theta)$
$coeff_i=.5*\rho*S*V_i^2$
Lift ins $_i$=$coeff_i*\cos\alpha*Cd_i$
Cd_i is based on either C_d up or C_d down depending on motion of wing
Thrust ins $_i$=$coeff_i*\sin\alpha*Cd_i$
Cd_i is based on either C_d up or C_d down depending on motion of wing
Forward Velocity=$2*T_{all}/(\rho*C_{dfrontal}*A_{frontal})$
Aero Lift 1 wing = $.5*\rho*$Forward Velocity$^2*S*C_l$ (assumed as $3*\alpha$ based on wing shape)

Integration Values are determine using the trapezoidal method, All other values are unit conversions.

Appendix F – Control System Components Definition

Fuel cell: It's the power engine which produce electrical energy in order to pilot all uavg elements.

Fuel cell servo control: this component pilot the fuel cell , her alimentation , her energy production and the working substructure.

Energy: it's the energy needed by the fuel cell to produced electrical energy.

Ground robotic : it's compose of two motor tracks and a free wheel on back for the stability. Each track are drive by an electrical motor.

Ground robotic servo control : this component regulate the electricity intensity for each motor in order to modify the rotation speed and the torque of its.

Front Wings: it's compose of 2 wings placed on the front of Pegasus which blinked together in order create the permanent sustentation at each part of the flight. Wings blinking are control by an electrical motor whereas angle attack is control by a linear step by step electrical motor and the wing camber by piezoelectric element.

Back Wings : They are also compose of 2 wings but place set back from front wings. Wings blinking are control by an electrical motor whereas angle attack is control by a linear step by step electrical motor.

Front and back Wings servo control : those components pilot each motor which permit to move respectively front and back wings.

Payload : this part group all materials needed for the aim of the mission : camera , articulated handle…

Payload servo control: this component pilot all payload element used for the mission

General calculator : the calculator analyse in real time the situation due to sensors and servo control information. It send information to each servo control to pilot Pegasus. It's aliment in electrical energy by the fuel cell.

Radio receptor: it send information to the headquarter and may received information to reprogram the mission. If there is problems

Data mission: this element permit to receive data mission and program the calculator.

Radars : give information on the external environment which permit to pilot Pegasus.

GPS : give the exact position of Pegasus.

Flying sensors: group all sensors used for flying part mission.